14. Construction Machinery

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In this chapter the most common classes of machinery found on construction sites will be presented. For the purpose of this chapter the authors focus on construction machinery and equipment applications in the building and public utility sectors of the construction industry. The classes of machinery and equipment for earth, concreting, assembly, and finishing works described in this chapter are used not only in these two construction industries, but also in road, bridge, and railway building; pile, tunnel, and water foundation; the opening of mines; the building of natural gas and petroleum pipelines; sewerage systems; cooling towers for the power industry; and other industrial building structures.

One should note that specialized equipment ensuring the efficiency, high quality, and safety of work during the realization of structures is used in almost all these kinds of construction. Even a brief description of this equipment would require a separate publication. For example, in road building alone 63 types of machines (see the draft International Standard ISO/FDIS 22242) are used. In the final part of this chapter the state of automation and robotization of construction machinery is presented.

14.1 Basics

14.1.1 Role of Machines in Construction Work Execution

Construction work is to a large extent hard and labor intensive and often poses a health hazard. This is due to the fact that building production involves handling large masses of materials and that some of the materials, such as lime, paints, industrial chemical products, and asbestos, are detrimental to human health. In addition, most construction works are carried out in the open.

The mechanization of construction started with hard physical work and labor-consuming effort, such as earth works and the horizontal and vertical transport of materials, only later embracing finishing works.

Construction work mechanization is inseparably linked with the technologies used in construction and so one can distinguish work mechanization by the different branches of construction (e.g., housing, public utility building, civil engineering, industrial building, and power facility building) or by particular kinds of work, e.g., earth work, assembly, and finishing work.

The transition from craft methods to a more economically effective form of industrial building, using a wide range of prefabricated units, gave an impetus to the development of more efficient machines for the assembly of such units as well as machinery and equipment for concrete works.

The mechanization of construction is a worldwide phenomenon and determines the development of this industry.

Through construction mechanization one can achieve the following goals:

- Speed up the rate of work in comparison with manual methods and so shorten the construction cycle.
- Reduce labor consumption, increase production capacity, and reduce work costs.
- Make work in construction less arduous and so more attractive.
- Improve work safety (construction is the most hazardous field of human activity).

Particularly rapid advances in construction mechanization were made after World War II in response to the urgent need to increase construction production capacity to provide the population with housing and improve standard of living. This was done by developing the construction machine building industry and new technologies consisting of the assembly of building structures from prefabricated units. Construction mechanization covered the following kinds of work: earth work, vertical and horizontal materials transport, materials handling, assembly, and finishing work (including external and internal plastering, painting, terrazzo and wooden floor sanding, and element fixing).

Mechanization is the primary factor contributing to an increase in productivity and it should be economically worthwhile, which is achieved through the intensive use of modern machines in good working order.

Definitions

Construction machine: a device whose function is to increase or replace human or animal physical force in carrying out construction processes.

In the field of construction machinery one can distinguish two general classes of machines: technological machines (for processing raw materials and/or semifinished products) and transport machines (for changing the location of building elements and materials).

Construction work technology: a method for carrying out construction work.

Mechanization of construction: activities covering the application of machines, equipment, and mechanized tools to carry out manufacturing processes in construction.

14.1.2 Development of Construction Machinery – Historical Outline

The available historical data indicate that cranes form the oldest class of construction machines invented by humans. Cranes were known in Greece as early as the

5th century BC. They were used for transporting structural elements vertically and horizontally and putting them in specified places, among other tasks, in the construction of magnificent temples. Greek cranes incorporated structural components such as toothed and worm gears, pulley blocks, rope drums, supports, and power units in the form of levers mounted directly on the hoisting winch's shaft, or various treadmills.

Figure 14.1 shows a derrick commonly used in both ancient Greece and Rome, with a mast in the form of the letter "A". The hoisted block is grabbed by a crampon. The winch is turned by means of two levers and the mast's inclination is adjusted by guy-ropes.

As late as the second half of the 19th century, i. e., until the industrial revolution, cranes were driven by people or, less commonly, by animals. Treadmills, including treadwheels with steps to be climbed, or pole windlasses were used as the driving devices [14.1] (Fig. 14.2).

Historically, the next class of construction machines to be invented was pile-drivers. These were needed to build structures (including temples) on weak ground and bridges. The first pile-drivers were very similar in their design to cranes. A simple medieval pile-driver consisted of a tripod, a rope sheave, and a rope with a hook on which a heavy stone block was hung. The dropped block would drive a pile into the ground. Devices working on the double-arm lever principle and a hoisting winch were employed to pull out such piles.

Towards the end of the 19th century pile-drivers with a guided drop weight began to be used. Later floating pile-drivers powered by a paddle waterwheel were introduced. Also the pulling up of the pile hammer was improved: the work of several people hoisting the pile hammer to its upper position by simply pulling the rope was replaced by a treadwheel or a treadmill.

The next class of construction machines developed were dredgers [14.2], which were used to build waterways and deepen ports and canals. The first record of the design of a gouge-dipper dredger dates from 1420, presented by Venetian Giovanni Fontana (Fig. 14.3).

The Fontana dredger was installed on a pontoon and its working tool was a dipper moving in a chute with a sharp metal tip. First the lowered dipper was inserted into the ground under its deadweight and then the winning was detached by the gouge-dipper as the latter was pressed into the ground. The winning was brought to the surface by pulling the dipper up in the chute.

The gouge-dipper dredger was the precursor of a whole family of dredgers. Later scraper dredgers,

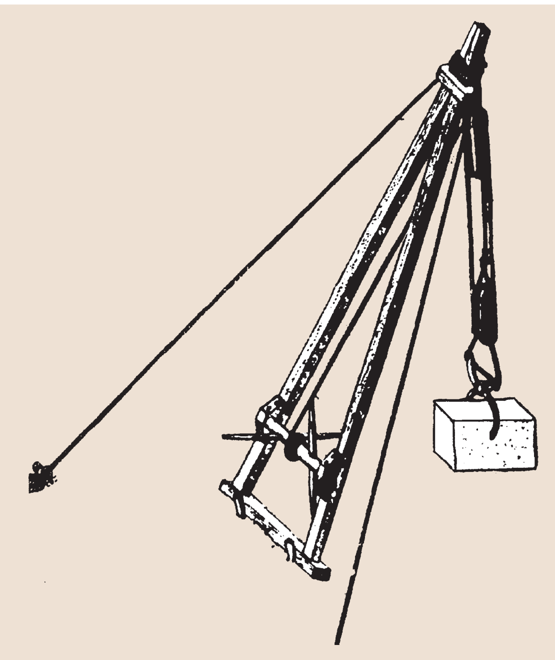

Fig. 14.1 Derrick used in ancient Greece and Rome

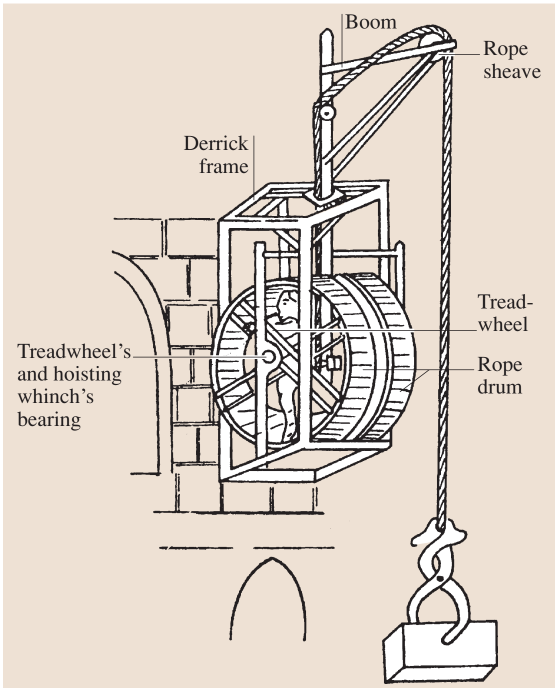

Fig. 14.2 Treadwheel-type boom derrick placed on erected building's wall

clamshell dredgers, dipper dredgers, dipper-scraper dredgers, wheel dredgers, and carding dredgers were designed.

The working mechanisms were driven via hoisting winches by treadwheels, pole windlasses or treadmills powered by men. The exception was a horse-driven 16 m^3/h-capacity dredger with a 0.66 m^3-capacity dipper, built in the USA around 1820.

The development of dipper dredgers gave French designers the idea of putting similar machines to work on land, and so excavators came into being [14.2]. The first excavator designs, although unrealized, appeared in the first half of the 17th century [14.2].

The beginnings of the development of construction mechanization and a breakthrough in construction machine building are associated with the industrial revolution in the UK in the middle of the 18th century.

The most important device in the industrial revolution was the steam engine, improved by Thomas Newcomb (1683–1729) and James Watt (1736–1819). As a result of the Industrial Revolution and its spread to other countries, rapid population growth combined with the expansion of large cities and the development of road, water, and sea transport occurred. The massive and rapid construction of railway lines, roads, canals, and ports involved large-scale earth works. Construction machines, initially powered by steam engines and later combustion engines and electric motors, appeared. The first construction machines in which power drives were employed were dredgers, most commonly bucket-ladder dredgers, used for extracting the winning from the bottom of rivers and canals and for building ports. They were first built in the UK and then in the USA, Russia, and France, and worked in conjunction with loading bridges, transport-tow vessels, and rail transport for carrying off the winning.

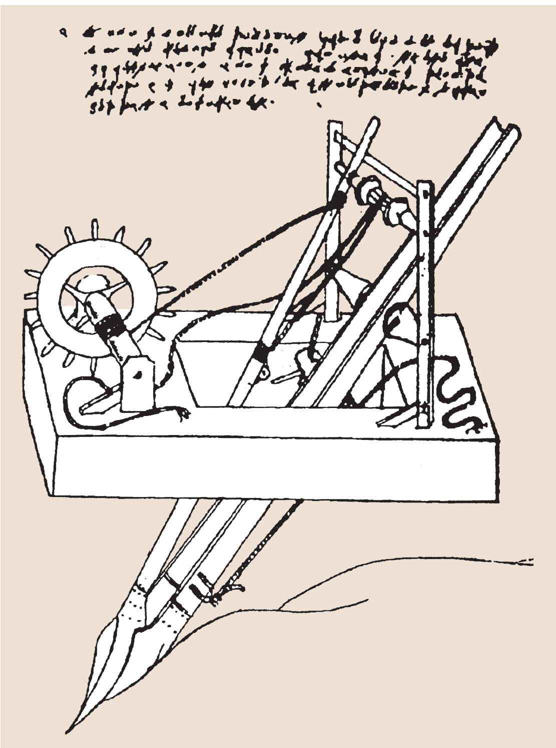

Fig. 14.3 Giovanni Fontana's gouge-dipper dredger

The development of the railway system boosted demand for related construction works, track, and rolling stock. Embankments, tunnels, and bridges were built, and tracks were also laid.

In the development of construction machinery one can distinguish the following landmarks:

- The development of the first steam-powered earth-moving machine in 1776. This was a dipper dredger used for dredging the canals in the port of Sunderland.
- The building of the first steam bucket-ladder dredger by Samuel Bentham in 1802 for work in the port of Portsmouth (UK).
- The construction of a floating bucket-ladder dredger, called the *Amphibious Digger*, by Oliver Evans – the pioneer constructor of steam engines in America – for dredging the river and port of Philadelphia in the years 1800–1804.
- The invention of the steel cable by Albert in Germany in 1834, the use of which greatly contributed to the development of cranes.
- The building of the first single-bucket excavator, called the *American Steam Excavator* or the *Yankee Geologist*, by William Smith Otis in the USA in 1836 (Fig. 14.4). Otis's machine has been a symbol of construction mechanization to this day. The proof of its originality and technical excellence is the fact that it set the direction of the development of excavators for 140 years. Otis's first machines were used in the construction of the Baltimore–Ohio railroad.

Otis's excavator with a 1.15 m^3-capacity bucket replaced the work of 80 diggers. Its high economic efficiency significantly contributed to the development of the excavator, grab-dredger, and crane building industry.

The total production of excavators and dredgers in the USA in 1880 reached 1000 units per annum, and a considerable number of them were exported:

- In 1850 Briton William Fairbairn (UK) developed an arch crane jib made from two riveted plates and then steam-driven cranes.
- In 1861 in Germany Nicolaus August Otto developed a four-stroke, spark-ignition combustion engine.
- In 1874 the company the Aveling & Porter (UK) developed the first steam-driven wheeled crane, called *Little Tom*. In the same year a gantry crane with a truss bridge girder was constructed in north Germany.
- Bucket-ladder dredgers, loading bridges, locomotives, and steam-powered transport-tow vessels were built in France for the construction of the Suez Canal in the years 1865–1869.
- The construction of the Manchester–Liverpool Canal in the UK in the years 1887–1898. Fifty-eight British-made (Ruston, Smith, Whiteker, and Wilson) single-bucket excavators, 18 Priestman clamshell excavators, and many bucket-ladder excavators and dredgers were used to carry out earthwork amounting to 38 million m^3.
- In 1897 Rudolf Diesel built the first compression-ignition engine.
- The development of bucket ladder excavators in France, Germany, and the USA in the second half of the 19th century.
- In 1890 the Osgood Company (USA) built the first electrically driven railway excavator.
- Around 1900 the first traveling tower cranes with a hoisting capacity of 0.25–5.5 Mg were built in Germany and France.
- The building of the Panama Canal under the control of the USA in the years 1904–1914. About 100 railway single-bucket excavators were with a bucket capacity of 2–2.9 m^3 each were used on the building site. They were American-made machines supplied mainly by the Bucyrus Steam Shovel and Dredge Co. (South Milwaukee) and the Osgood Dredge Co. (Troy, NY).

Besides these excavators many other steam-driven machines, such as dredgers and narrow-gauge railways for transporting the output, were used in the construction of the canal.

The 20th century brought rapid development of construction machines. Steam engines were replaced by combustion engines and electric motors, which were

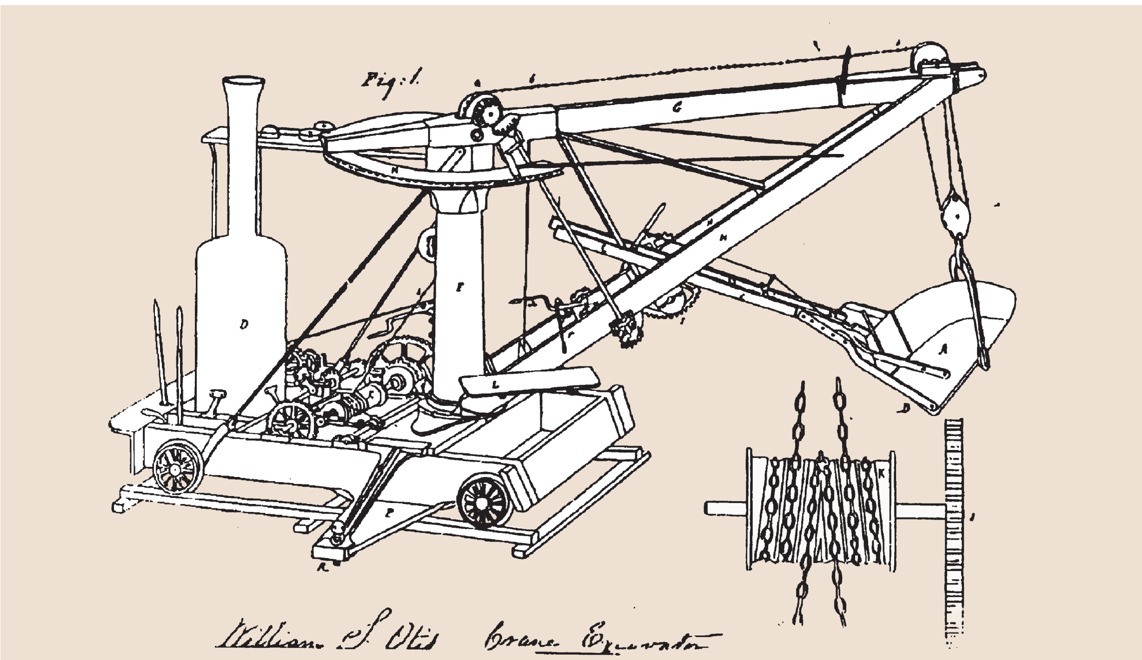

Fig. 14.4 Patent drawing of excavator signed by W. S. Otis on 24 February 1839

easier to operate. High-strength structural materials, hydraulic and pneumatic drives, and control systems incorporating electronics, computer technology, and microprocessors were introduced. As a result of these innovations the performance of construction machines improved and their range of application was extended.

American companies have contributed greatly to the development of construction machinery. For example, Powling and Harnischfeger was one of the first companies to manufacture crawler cranes at the end of World War I and Bucyrus-Erie was the first company in the world to present in 1946 a traveling hydrocrane with a telescopic jib. Several classes of modern construction machines will be described in the next sections of this chapter.

14.1.3 Classification of Construction Machinery

The various construction machines can be divided into two classes. One class comprises specialized machinery exclusively for construction-assembly work while the other includes general-purpose machinery used in various industries. This means that one should distinguish between the terms: *construction machinery* and *machinery used in construction*.

In many cases, however, this distinction is not clear cut. This is so, for example, in the case of motor transport means (trucks, semitrailers, trailers, and tractors), wheeled cranes used for reloading different materials, and power shovels, bulldozers, and front loaders used also in surface mining and in loose-material reloading yards. Another example is the use of helicopters for the assembly of tower structures.

In the literature on this subject one can come across various methods of classifying construction machinery, usually according to the kinds of construction work for which it is used, its function or design.

The classification found in [14.3] can be regarded as the most reliable classification of construction machinery and equipment. This document is not yet an international standard but may become one in the future.

In this report, construction machinery and equipment are divided according to the kinds of work for which they are used into the following seven classes:

1. Earthmoving machinery and equipment
2. Foundation engineering and soil compaction machinery and equipment
3. Machinery and equipment for manufacturing, transporting, and processing concrete and mortar and for reinforcement and formwork
4. Lifting and access machinery and equipment (scaffolds and work platforms)
5. Specialized machinery and equipment used in building construction (e.g., machinery for roadworks and pipe-laying)
6. Equipment for installation, finishing work, and maintenance
7. General-use machinery and equipment used in construction processes

The above classes are divided into subclasses and then into types. Readers interested in the detailed classification are referred to the report itself.

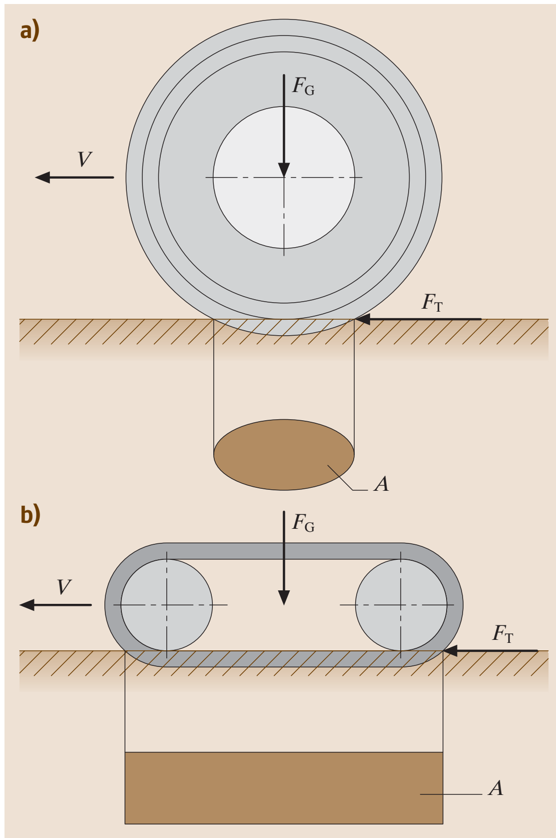

Fig. 14.5a,b Comparison of a wheel **(a)** and a tracklaying chassis' **(b)** footprints

14.2 Earthmoving, Road Construction, and Farming Equipment

It is decisive for human action to use tools, devices, and machines. For a long time man has been making use of machines for construction and agriculture. The huge buildings of antiquity could never have appeared without the application of construction machinery. However, agricultural machinery – especially those according to the EU machinery directive [14.4] – did not emerge until the 18th and 19th century, with the UK and the USA being the first to make use of them [14.5]. A particular problem to be addressed for agricultural machinery was the necessity to be mobile, and today it is still mobility which is one of the most important functions of earthmoving, road construction, and agricultural machines. This is the feature which distinguishes them from stationary machines such as machine tools. Therefore, they are summarized as *mobile working machines*. Due to their requirement for mobility, the following issues are important for this kind of machine and their construction:

- The machine must be connected to an energy source.
- Energy is needed for running the device or the drive.
- The machine can move actively (automotive) or passively (pulled).
- It must be equipped with a (wheel or chain) chassis to supply the tools with energy.
- It must be possible to integrate all components of the machinery system (drive, sensors, actors, etc.) into the vehicle.

Another important feature of earthmoving, construction, and agricultural machinery is the fact that they are designed to fulfil specialized working functions and to be part of complex processes in the area of construction or agriculture.

14.2.1 Soil Science and Driving Mechanics

Soil Composition

Regarding mobile working machines, the soil is of special importance in two regards:

- Mobile working machines move on the soil. Every vehicle requires ground to move on. Depending on the type of chassis used, the drive force must be introduced into the ground in some form, which means that the soil has to take up the driving power; otherwise the wheels or chains would spin. In a broader sense, even roads made of asphalt or concrete must be regarded as soil, representing artificial, manmade hard soils (rocks) that provide a good driving surface.
- Soil is the main resource for plant production and, indirectly, for animal production, thus serving man's demands. Regarding its important role, soil cannot be replaced by any other resource. Soil fertility is mainly dependent on the activity of soil bacteria, fungi, algae, and other microbes. Mobile working machines, especially agricultural machines, are closely linked to this resource, as they are utilized for plant and animal production. The same is true for forestry machines and municipal machines. Earthmoving machines, which are also mobile working machines, also work mainly on soil.

A more detailed description of soil follows, in terms of both its physical and biological features.

Soil consists of various components:

- Solids
- Liquids (water)
- Gas (air)

This distribution of solid, air, and water can be represented as a three-phase system. Soils are classified depending on their aim and application. So, in the area of earthmoving, for rock production, the decisive criteria are different from those in the area of agriculture, which concentrates on soil fertility. An example of agricultural soil classification is the *World Soil Classification* initialized by the Food and Agriculture Organization (FAO) [14.6]. Rock may be classified according to the ISO standard 14689-1 entitled *Geo-technical Investigation and Testing – Identification and Classification of Rock* [14.7]. Apart from these international classification systems there are various national ones [14.8].

Chassis Types

The chassis can be regarded as an interface between the mobile working machine and the ground; two main groups can be distinguished (Fig. 14.5):

- Wheel chassis
- Tracklaying or crawler chassis

In addition to these two groups, there are special-purpose chassis types such as walking chassis to move machines, e.g., in open-cast mining. The driving resistance can be calculated by multiplying the force due to

gravity by the tractive resistance. The most important difference between a wheel chassis and a tracklaying chassis is that a chain tread has a higher driving resistance than a wheel chassis. This has a positive effect on force transmission between the wheel and the soil, reducing soil pressure. However, a wheel chassis permits higher driving speeds than a tracklaying chassis, which turns out to be advantageous, and, with their simpler construction, they can also be used for vehicle suspension.

Wheel Chassis

Force transmission between the wheel and the soil is very complex, being determined by various parameters:

- Penetration into the soil (i. e., soil load-bearing capacity and structure)
- The variety and construction of wheel
- Load and its distribution over area
- Air pressure
- Suspension
- Tyre profile

The roll resistance force value determines the distance between the two vertically acting forces weight and vertical acting force in the case of the driven wheel, and also the angle between the weight and vertical acting force with the pulled wheel (Fig. 14.6).

When the wheel is driven and, additionally, when the traction forces F_T have to be transmitted, e.g., by pulling a trailer or a plough, the propulsion torque is in balance with the soil force.

Figure 14.6 shows the forces acting on a pulled wheel in a simplified way. The driving torque is determined as follows:

$$M = F_T r + F_G f \,, \qquad (14.1)$$

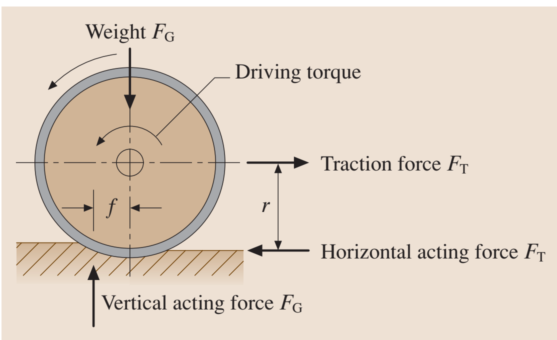

Fig. 14.6 Simplified forces model for a rigid wheel (after [14.9])

where M is the driving torque, F_T is the driving power, F_G is the weight, and r is the effective roll radius. The tractive resistance ρ of a four-wheel tractor is 0.13–0.18 on sand. On concrete or asphalt the tractive resistance is 0.015 [14.9].

Figure 14.7 shows the relation between the wheel perimeter force and the slip. The wheel perimeter force depends on the roll resistance and the driving power.

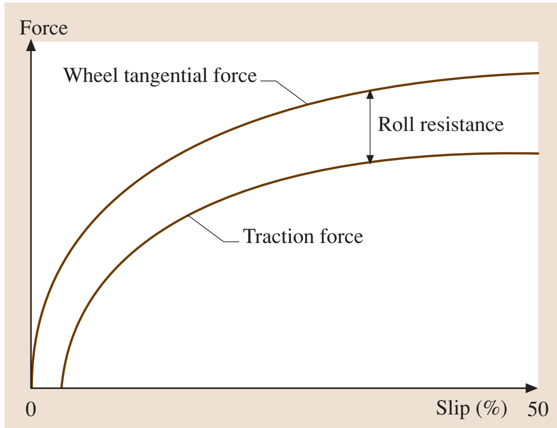

Fig. 14.7 Roll resistance force F_R and wheel traction force F_T depending on the slip σ [14.9]

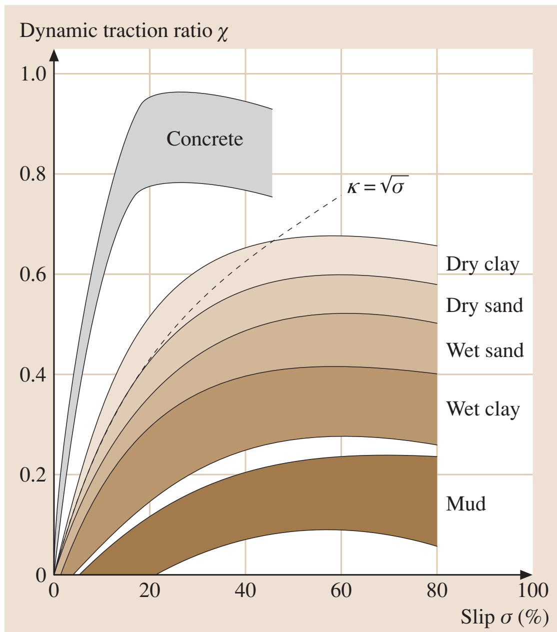

Fig. 14.8 Dynamic traction ration with different soil types (after [14.10])

There is always slip because the roll resistance force F_R has to be overcome to move the vehicle. Indeed, the slip is always small and positive (Fig. 14.7) and, in general, driving is not possible without slip.

The dynamic traction ratio expresses the ratio between the maximum traction force and the wheel load (including the wheel's own weight)

$$\kappa = \frac{F_T}{F_G} . \quad (14.2)$$

The dynamic traction ratio is determined by measurement. Above all, it depends on the slip σ, as shown in Fig. 14.8. As is shown by this curve, the softer the soil, the lower the propulsion that the wheel can transmit. We can also see that the wheels tend to spin faster and more easily for a flat curve profile. Approximately the following formula describes the behavior up to slip of 30%

$$\kappa \approx \sqrt{\sigma} . \quad (14.3)$$

The curves shown in Fig. 14.8 are influenced by three features:

- Tyres and stud deformations
- Soil deformations
- Gliding on the contact surface

14.2.2 Tyres

Tyre Structure

Figure 14.9 shows the general structure of a tyre. The tyre consists of a casing and a contact surface. The casing is also laterally covered by rubber material. The wire-wound core keeps the tyre inside the rim's bead. Nowadays, drive wheel tyres are equipped with a hose in most cases, as the driving power transmission would otherwise be restricted.

Consisting of several tissue layers, the casing provides the tyre with stability. According to the casing's construction, different tyre construction varieties can be divided into the following groups:

- Biased ply construction (Fig. 14.9b): The tissue layers run from one bead to the other with 45° staggering. This construction variety is relatively easy, making the tyres cheaper.
- Radial ply construction (Fig. 14.9c): In this tyre type, also called belted tyres, the tissue layers run radially from bead to bead. Around this inner layer, on the contact surface, there is an additional contact surface consisting of several tissue layers (the belt). Thus, the contact surface gains greater stability. Due to the soft casing, the tyre exhibits much greater spring deflection and thus a larger footprint than that produced by a diagonal tyre. Additionally, there is:
  - Better force transmission
  - Reduced soil pressure
  - Reduced roll resistance
  - Softer spring deflection of the tractor
  - Extended life of the contact surface

Force Transmission Between Tyre and Soil

Various forces are transmitted from the tyre to the soil. As already mentioned above, the material properties of the soil considerably affect the driving mechanics.

The highest pressure transmitted by the tyre to the soil, and thus the greatest degree of compaction, is always found at the center of the contact surface. However, the dimensions of this contact surface depends on the deformability of the ground. This means that the footprint increases with a softer soil, i. e., the contact surface pressure decreases. In any case, the integral of the pressure stays the same (Fig. 14.10).

The soil pressure arising from the machine's weight considerably influences the soil fertility, thus being of special importance for agricultural machines. It

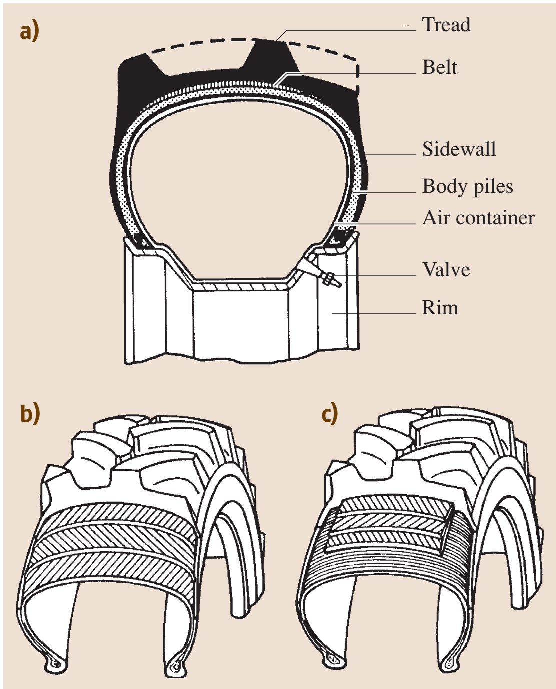

Fig. 14.9a–c Cross section through a tractor tyre with rim (after [14.10], description in text)

is important to minimize the negative impact of increased soil pressure by choosing an appropriate set of tyres. Due to internal friction in the soil, the pressure continuously decreases with distance from the footprint. However, the isobars, i. e., the lines of equal pressure, reach deeper into the soil with increasing load (Fig. 14.11). When the subsoiler does not work efficiently enough, detrimental soil compaction may occur.

The contact surface pressure is a decisive feature regarding the growth of new plants and soil ventilation. For solid ground, the following empirical rule apples: due to the casing's rigidity, the contact surface pressure on the footprint is about 0.03–0.04 MPa higher than the inner tyre pressure with radial tyres, and 0.05 MPa higher with diagonal tyres. For solid ground, this pressure is almost the same across the footprint because the deformation of the tyre is much greater than that of the soil [14.9].

In the case of earthmoving and road construction machinery, preserving soil fertility is less important. It is much more important to concentrate on features such as load-bearing capacity, insensitivity to stones, and good traction capacity. In the case of compaction rollers, it is precisely compaction which is important. In any case, it is necessary to consider these effects and their relations with the corresponding application.

Chain Chassis

Apart from tyre chassis, earthmoving and road construction machines mainly use a chain or caterpillar chassis. A caterpillar track consists of individual links arranged in front of the machine following the driving direction, thus serving as a lane for the machine. The chain has to simultaneously take up all forces resulting from traction and the load of the machine itself as well as possible lateral forces caused by steering movements. Similar to the tyre–soil system, the dynamic traction ratio between the chain and the soil depends on a number of parameters. Usually, the chain–soil system permits the transmission of large traction forces. Due to its footprint, which is larger than that of a wheel chassis,

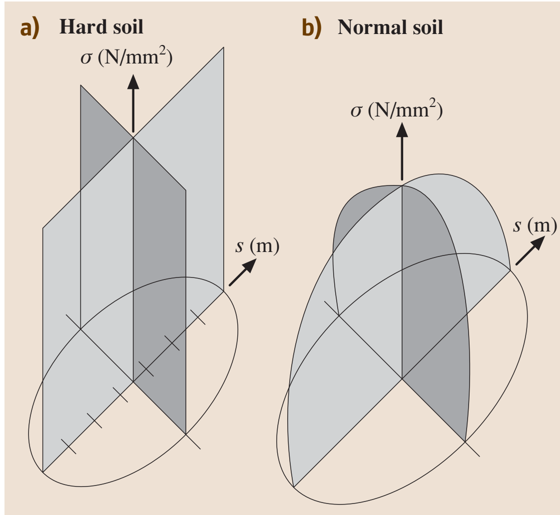

Fig. 14.10a,b Qualitative description of the pressure tension fields in the soil below the tyre (after [14.11])

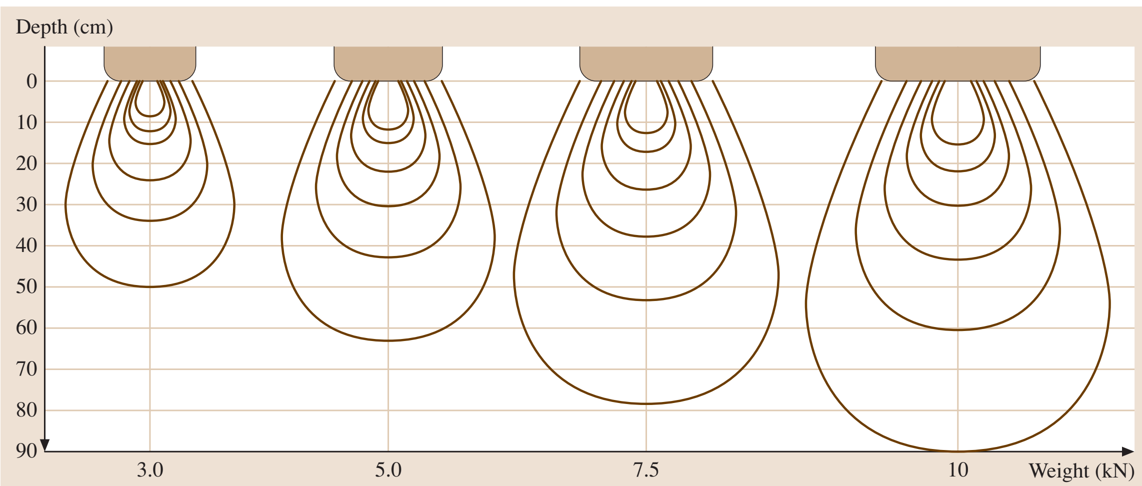

Fig. 14.11 Influence of the tyre load on the soil pressure (air pressure 0.082 MPa in all cases) [14.9]

the soil pressure is lower. Another feature of the chain chassis is its good stability, which is of considerable importance for hydraulic excavators.

Rubber belt tracks combine the advantages of both systems. They are applied in mini-excavators and road pavers. In the area of agriculture, rubber belt tracks are used in tractors equipped with high engine powers designed to work on the soil. Rubber belt tracks suffer from less vibrations compared with steel chains, while almost the same driving speeds are possible as with standard tractors. Moreover, they cause less damage to the road surface [14.12].

Figure 14.12 shows the general construction of a chain track. It consists of the chain, the base plate, the track rollers, the support rolls, the driving wheel, the guide wheel, the tensioning device, and the track frame. A chain chassis consists of at least two chain tracks. The guide wheel usually has only one guide profile and, using the chain tensioning device, can be shifted in order to tighten the chain. The smaller track rollers on the bottom serve to support the machine against the chain. The track rollers are designed to transmit even lateral forces emerging from steering movements or slope forces. There are various arrangements for the tractive turas. Whereas the conventional variety is preferred for hydraulic excavators and cold milling machines, large dozers are mainly equipped with the delta arrangement. Advantages of the latter include that the drive is protected against pollution and that driving performance is better.

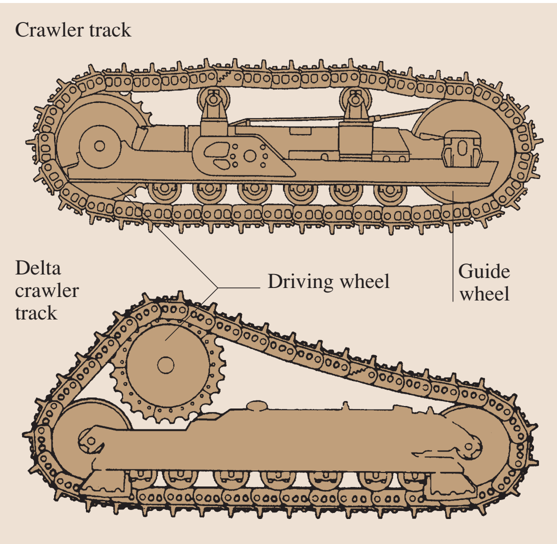

Fig. 14.12 General construction of a chain track

Steerings

The vehicle's chassis and the planned application are decisive for the choice of the steering system to be utilized. The steering considerably influences a machine's steering stability, driving security, stability, and manoeuvrability. In the case of tracklaying vehicles, the only useful steering method is skid steering. With a wheel chassis, vehicle steering is achieved by applying different driving speeds to the left and right chain tracks. A wheel chassis uses axle pivot steering of one or both axles, articulated steering or a combination of articulated and axle pivot steering. Whereas tractors mainly use axle pivot steering, earthmoving machines are equipped with the steering varieties shown in Fig. 14.13. The articulated steering variety is applied mainly in wheel loaders and is characterized by a two-part machine frame. An articulated chassis connects both frame elements, facilitating hydraulic displacement of the elements around the vertical axle. The steering angles are 40–50° to both sides. Given an additional movement around the vehicle's lateral axle, this articulation results in a center pendulum pivot steering system. Such an articulation replaces a pendulum axle. The characteristic features of the articulated steering are:

- Very good manoeuvrability
- The rear wheels are running in the same track as the front wheels
- Slim machine construction is possible
- When turning the wheels, the center of gravity is displaced, reducing the maximum load capacity

Axle pivot steering is an alternative to articulated steering. In most cases, tractors are equipped with axle pivot steering, on one or both axles. Various types are used in the case of all-wheel drive:

- Driving curves: Here, the wheels are turned so as to move the machine around the intersection point of the verticals or the prolonged axle. To achieve this, it is only necessary to steer one axle; in most cases, the front axle is used for steering.
- Four-wheel crab steering: The wheels are turned so as to move the vehicle laterally in a line parallel to its longitudinal axis.
- Circular driving: The wheels are turned so as to turn the machine on the spot.
- Diagonal driving: All four wheels are turned by 90° so as to move the vehicle diagonally to the vehicle's longitudinal axis.

The characteristic features of a vehicle equipped with axle pivot steering are:

- With axle pivot steering of the front axle, there are four tracks. which causes the driving resistance to increase on yielding soil.
- It is not possible to *free* the vehicle with only. one turn of the wheels as is possible with articulated steering.
- Good manoeuvrability is possible for all-wheel-driven vehicles.
- Good stability.
- Steering and turning the wheels requires space.
- Four-wheel crabbing facilitates lateral displacement of the machine.

Apart from these general types, there are also combinations of articulated steering and axle pivot steering.

14.2.3 Earthmoving Machinery

Earthmoving designates all modifications of the Earth's crust regarding position, form, and density. Among others, this might include:

- Excavate soil
- Digging ditches and soil excavations
- Raw material extraction
- Soil transport
- Material installation, e.g., for road and embankment construction
- Material compaction

Along with structural and civil engineering, earthmoving is another branch of construction, being applied in different cases.

Wheel Loaders

Wheel loaders or shovel dozers are extremely mobile machines with universal application possibilities. Their main task is to remove soil, as well as to load, transport, and locate material [14.13]. The working level is the same as the driving level, or even slightly below in some cases. Wheel loaders can be classified into:

- Front-end loaders
- Swing loaders
- Overhead loaders
- Telescopic loaders
- Skid steer loaders

The chassis and the steering variety used (articulated or axle pivot steering) are other criteria that can be used to distinguish between types of wheel loaders.

The most important variety of the wheel loaders listed above is the front-end loader. Here, the working device is mounted on the front part of the machine frame. It consists of a multiple bar linkage powered by hydraulic cylinders. This hoisting gear is usually equipped with a loader shovel. When loading soil, the shovel is lifted to the surface level. Keeping this position, the whole machine has to drive into the material. Thus, apart from the driving resistance, the machine also has to compensate the shovel's penetration into the material and filling resistance. When the shovel is filled, the hydraulic cylinders are placed into the transport position. Wheel loaders are mainly driven by diesel engines. Generally, a wheel loader has to be equipped with drives for the working devices, the steering units, and the chassis. Depending on the machine's power class, various drive varieties are used:

- *Wheel loaders of maximum* 59 kW. These wheel loaders mainly use hydrostatic drives. The efficiency factor, which is worse than that of mechanical drives, is compensated by lower costs and broader application. In general, the resulting maximum speed is 25 km/h and, in most cases, steering is by axle pivot.

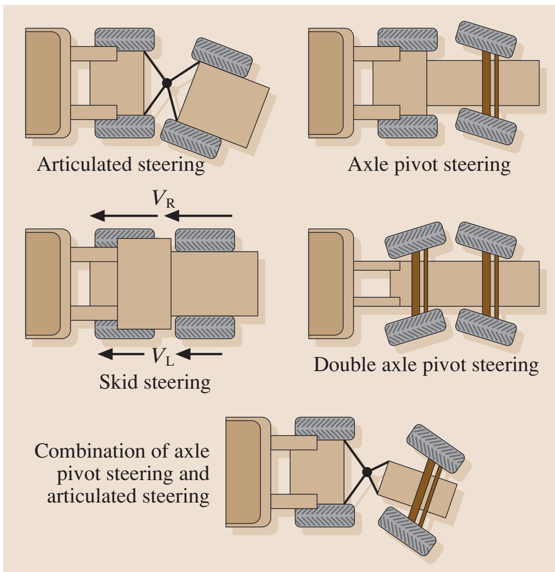

Fig. 14.13 Steering types

- *Wheel loaders of max.* 110 kW. The drive of these wheel loaders is realized by a power shift transmission and a torque converter. Some machines also use hydrostatic drives. Either articulated or axle pivot steering is applied. Maximum driving speed is about 40 km/h.
- *Wheel loaders of more than* 110 kW. Large wheel loaders are always equipped with power shift transmission, a torque converter, and articulated steering. Their maximum driving speed is 35–45 km/h. These machines often have a general operating license for general traffic.

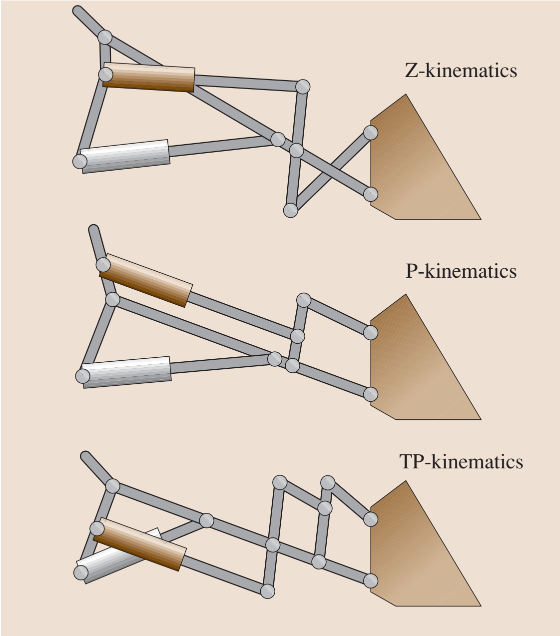

Fig. 14.15 Kinematics of a wheel loaders' working devices

Apart from driving power, there must be sufficient power for the working devices. Usually, the lifting force and the lifting speed of the working devices are adjusted, aiming to minimize the time period necessary for one loading process. Additionally, the lifting force is restricted to ensure stability of the machine. The working hydraulics usually consists of an open system with pilot control, which is used to supply the drives for steering and loading movements with an extra pump. Figure 14.14 shows an example of a hydrostatic drive of a wheel loader's working hydraulics.

The shovel's lifting and breaking off forces are mainly determined by the hydraulic cylinders and the kinematics applied. Figure 14.15 shows the kinematics used today. Modern machines are very often equipped with Z-kinematics due to the huge breaking off force effected by the good transmission of the shovel-tip cylinder mechanism. During the lifting process, Z-kinematics moves the shovel forwards and backwards while lowering the shovel. Parallel carrying is worse than with P-kinematics. The torque parallel (TP)-kinematic represents a compromise between both types of kinematics.

Regarding the driver's working place, wheel loaders are similar to tractors. As a rule, these machines are equipped with a driver cabin today, not only for safety

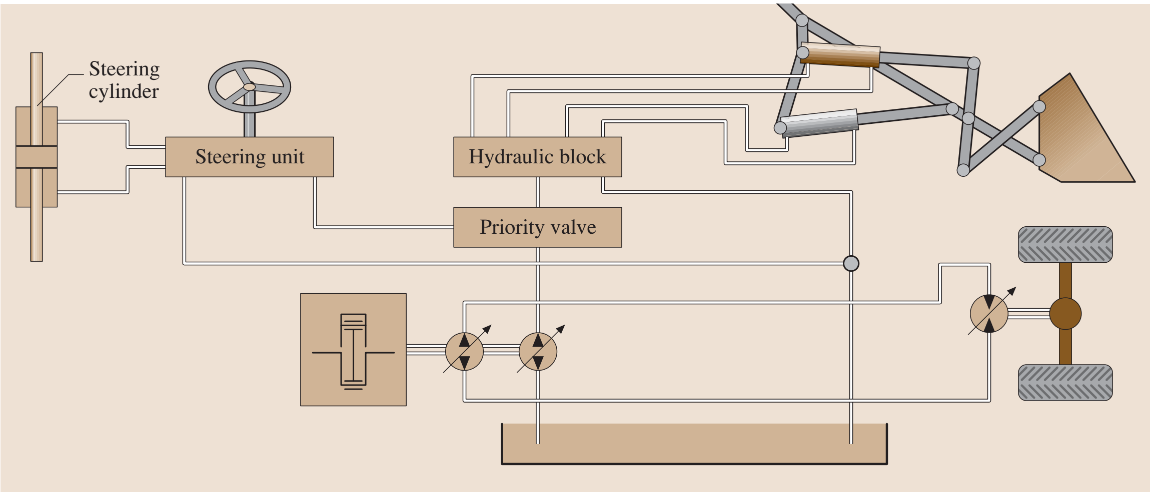

Fig. 14.14 Simplified hydraulic plan of a wheel loader

but also for driver comfort. Usually, the driver spends several hours operating the machine without a break. Therefore it is necessary to minimize stress and strain on the driver. The requirements for the driver's working place:

- Good view over the working device and the load during the whole working cycle
- Complete visibility without disturbances
- Huge door opening angle
- Safe and easy access to machine
- Air-conditioned cabin
- Adjustable driver's seat
- Ergonomic arrangement of the instruments
- Good vibration damping and reduction

The control system is also very similar to that of tractors. A controller area network (CAN) bus system is used for communication between the engine, operating device, and other machine components [14.14] (Fig. 14.16). The electronic components must be adjusted to rough machine usage, i. e., they must be well protected against vibrations, water, and dust. Nowadays, there are even microcontrollers that facilitate automated movement processes as well as supervising individual system states in order to prevent accidents.

Excavators

Excavators are loaders equipped with one or more buckets. A machine equipped with one bucket can only work discontinuously, i. e., carrying out intermittent process steps. In contrast to these *one-bucket excavators*, machines equipped with several buckets can work continuously.

Below we give a more detailed description of the so-called *one-bucket excavator* or cable dredger. This is an extremely large group, extending from special-purpose machines to universally applicable devices, so-called universal excavators.

The application area of the *one-bucket excavator* (or simply *excavator*) is extraction and handling of any kinds of goods. For this purpose, they use excavator spoons as well as digging and loading devices. Due to the advantages of hydraulic drive systems, excavators using this system are more important than those using a wire drive. The latter, however, are applied in excavators that are used to dig boreholes, which requires considerable working depth.

Today, the hydraulic excavator is the most important machine of this type, as hydrostatic power transmission and conversion are very advantageous in the case of excavators. Hydraulic excavators can be divided into single-purpose machines equipped with only one working device, and universal excavators, which can be equipped with various types of working devices [14.15]. There is a wide variety of such machines. Just regarding their own weight, they range from 0.5 t up to 800 t in the case of hydraulic excavators used in earthwork and open-cast mining. The smaller machines of 0.56 t are often called mini-excavators.

Another parameter used to classify these machines is chassis type:

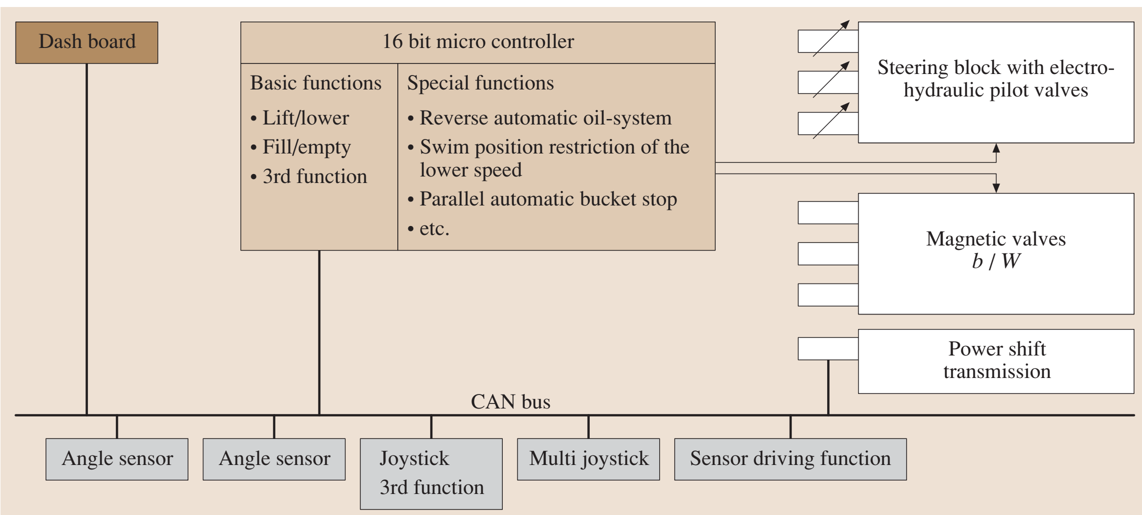

Fig. 14.16 Control system of a wheel loader (after [14.14])

- Tracklaying excavators, with crawlers or rubber-belted tracks
- Mobile excavators, which are equipped with a wheel chassis

Tracklaying excavators are designed for low driving speeds of up to 6 km/h. Normally, they just move on construction sites and do not participate in normal traffic. Mobile excavators or wheel excavators, however, do take part in the normal traffic. As is the case in agriculture, driving speeds are increasing considerably, with some machines traveling with a maximum speed of 50 km/h.

Figure 14.17 shows the basic construction of a hydraulic excavator. It is equipped with a revolving superstructure hinged to the chassis, which may be of chain or wheel type. The revolving superstructure carries the drive, including the oil and fuel containers as well as the cooling system, the filter, the control valve, the actuators, the driver's cabin, and the counterweight. The arrangement of these components is determined by the demand for balanced mass distribution, visibility, and ergonomics.

Another important component is the rotary transmission leadthrough, i. e., the connection between the revolving superstructure and the undercarriage. The hydraulic power needed for the drive is transmitted to the undercarriage by this rotary transmission leadthrough, which is a rotary pipe connection used to transport the fluid power from the rotating revolving superstructure to the drives installed in the undercarriage.

In the case of excavators, the hydraulic system is one of the most important components as all of the drives on the excavator are run hydrostatically. Using a pump power divider, a diesel engine distributes the power to several hydraulic cycles. There are always several power consumers to be supplied, which is a characteristic of excavator application. As a consequence, it is necessary to use control systems facilitating sensitive power-consumption adjustment and good energetic conditions as well.

Nowadays, an excavator's diesel engine is usually run at a rated speed, i. e., there is a constant initial speed of the hydraulic pumps. In some excavators the engine runs at a set of constant initial speeds. Variable-displacement pumps are used to adjust the flow rate depending on individual requirements. To achieve this, various systems can be applied, based on the load-sensing principle.

Hydraulic excavators increasingly make use of electrohydraulic systems. Microcontrollers also enable new possibilities for steering hydraulic devices and controlling and automating working cycles; for example, this kind of steering facilitates teach-in steering of individual motion sequences and automation of individual working cycles. Furthermore, there are even new possibilities regarding excavator management which do not involve running the diesel engine at a constant speed. In these systems, the diesel engine is optimally adjusted depending on individual requirements, which helps to reduce exhaust gas emissions and fuel consumption [14.17, 18].

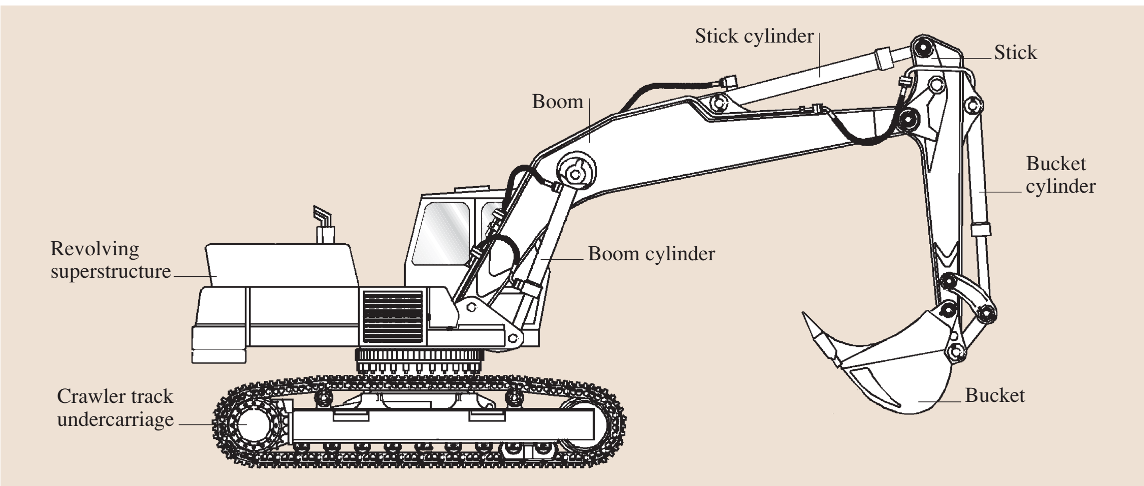

Fig. 14.17 Basic construction of a hydraulic excavator (after [14.16])

Graders and Scrapers

Graders are machines applied mainly in road construction (Fig. 14.18). The working device used is a blade designed for various applications. It is flexibly mounted between the front and the rear axle. In this position, the blade exhibits less vertical movement when crossing obstacles. In most cases, the chassis consists of pneumatic tyres. Apart from biaxial vehicles, triaxial ones also exist, with two axles combined into a tandem axle. In this case the single axle is used for steering, but machines with four-wheel steering or articulated steering have also been designed.

Graders are driven by a diesel engine with a capacity of 30–210 kW. Usually, the engine drives the tandem axle. Driving speed is 2–40 km/h, and can be accurately adjusted to the requirements of the individual task by using a driving gearbox. This is done through a manual transmission with up to 12 forward and 4 reverse gears. A grader's working weight is 5–30 t, and the wheelbase is 4.5 and 7 m. There are, however, devices that are much larger, weighing more than 90 t and with an engine power of more than 500 kW. For the vehicle's drive, various mechanical transmission types can be used, some of which have hydrodynamic converters or hydrostatic drives. Due to their advantages regarding various arrangement possibilities and considerable converting range, hydrostatic transmission has become increasing important in these machines. A decisive factor for the vehicle's drive is the nominal thrust force, which determines the machine's power capacity. The nominal thrust force depends on the engine power and the machine weight. A $2\times2\times2$ grader delivers a ratio of engine power to machine weight of about 9–10 kW/t. A $1\times2\times3$ grader is expected to deliver a ratio of about 7–8 kW/t [14.19].

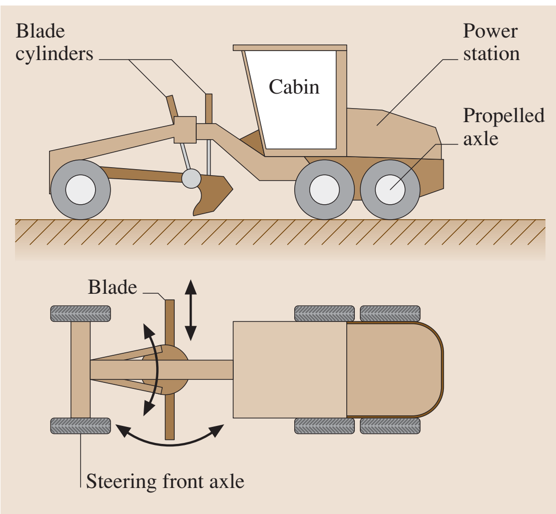

Fig. 14.18 Grader

Figure 14.19 shows a grader's blade positions. The specialized kinematics facilitate a large variety of blade positions, making the grader a universally applicable machine.

Depending on the chassis type, there are two types of scrapers: the wheel scraper and the tracklaying scraper with crawler, which is mainly utilized for difficult soil conditions. The excavating bucket consists of several parts. It has movable front and back sides in order to pour the material out of the container in a particular direction. Depending on the material and the machine, the cutting depth is 5–200 mm. The container's volume may vary from 1 up to 40 m^3, and the engine power may be as high as 700 kW. The driving speed necessary to transport the material can be 10–50 km/h. Conceptually, the front wheels are most strongly affected by the load, so they are driven. However, four-wheel drives are also in use [14.19].

14.2.4 Road Construction Machinery

Compaction Machinery

Compaction aims to increase the storage density and reduce the pore volume of material. Compaction machines serve to crush cavities and store soil grains at the highest possible density. The methods used depend particularly on the soil type:

- Grit and sand are compacted by vibration or pushing. Material of the same grain size is usefully mixed with other material in order to obtain a sieve classification. Pores between the coarse grains

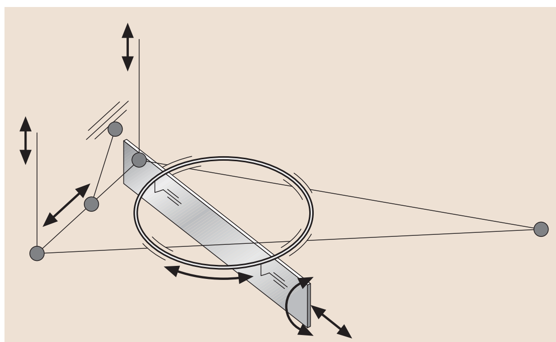

Fig. 14.19 Blade kinematics of a grader

should be filled with finer grains. The devices used are: vibration plates, vibration rollers, and blasting.
- Gravel and detrital rocks are compacted by pounding or pushing, smashing bulky chunks. The devices used are impact stampers, explosions stampers.
- Silt and clay are compacted by rolling or dispersing. There has to be sufficient water content in order to reduce the soil friction. However, the water content should not be lower than the pore volume to be achieved by compaction, otherwise water saturation will occur and the soil will adopt a plastic consistency. The devices in use are rammer butt rollers.

The compaction process consists of several individual processes:

- Ordering or distribution
- Destruction
- Pore water transport
- Displacement

Two main machinery groups can be distinguished:

- Statically working machines
- Dynamically working machines

It is also possible to classify them into rollers and vibratory plates.

Statically working rollers are among the oldest compaction devices, and today they exist in a huge variety. Depending on the number of roll bodies, they are classified into one-, two-, and trial-axle devices, or depending on their arrangement, into tandem or tricycle rollers. The roll body itself may be constructed as a flat roller, equipped with so-called sheep-feet roller, as a grid roller, or having rubber wheels.

Today, earthmoving and road construction make use of dynamically working rollers due to their better compaction performance. Usually, the rollers are equipped with vibratory stimulation; in some machines, there oscillation stimulation is also provided (Fig. 14.20). The unbalanced arrangement of masses and the rotation facilitate the introduction of vertical and rotating swinging into the drum or roller. The vertical swinging corresponds to vibration, and the rotating swinging provokes oscillation. By combining both movements it is possible to work on the material to be compacted according to its compaction potential [14.20]. Special measuring and steering systems enable optimum compaction. In these systems, there is a special focus on measuring the compaction. Modern systems are based on the principle of acceleration sensors that continuously measure the increasing rebound acceleration, comparing it with the result of previous measurements. In the case of the detection of increased compaction, the sensor produces a signal to carry out another drive over. For future documentation, the measurement data are additionally stored in relation as a function of area or position [14.21, 22].

With the vibration stimulation set to make the roller jump, the layer to be compacted will be more or less destroyed as it becomes uneven [14.21, 22].

The forerunner of the stamper was the iron hand stamper, which was used for paving work. In order to increase its stamping effect, engineers have developed heavier devices that are lifted either by excavators (the freefall stamper) or by blasting. The explosion stamper is used for compaction in narrow excavations or shafts. By igniting a fuel mixture, a rammer is thrown up (up to 46 cm), and then falls to the ground under the effect of gravity. This process provokes compaction of the fuel and re-ignition. Compaction of the soil is then effected by the explosion pressure and the rammer's rebound over a large number of strokes. A small stamper weighing up to 100 kg delivers compaction depths of up to 50 cm; heavier devices (500–1200 kg)

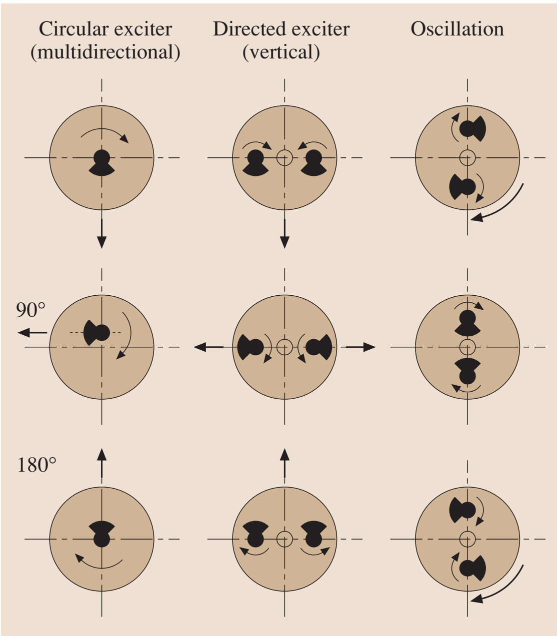

Fig. 14.20 The principle of vibration and oscillation stimulation (after [14.20])

achieve depths of 40–90 cm. Depending on the device used, the number of strokes is 60–80 strokes per minute. Vibratory stampers are used in narrow locations just like the explosion stamper. However, with a weight of 60–96 kg, they are lighter and only jump by 3–8 cm. Their multiple spring system is driven by combustion or electric motors with an average capacity of 2–3 kW. The material is compacted by the huge number of strokes (400–1000 strokes per minute) which cause a riddling effect. The vibratory plates are driven by combustion engines or electric motors. The vibrations are caused by an unbalanced mass vibration generator of various types of construction (directed and undirected vibration). Smaller plates have to be pulled to and fro, whereas larger devices are automotive, being steered by a shaft. It is possible to control their work direction, speed, and vibration.

Machines Used for New Road Construction

A variety of machines are used for road construction, and they shall be described in detail below. Figure 14.21 provides a rough classification of road construction machinery related to the individual construction processes.

Road pavers and slip-form pavers are used to build new road layers. Whereas road pavers are used to install special types of concrete, slip-form pavers are exclusively utilized to lay concrete. When laying asphalt, it is necessary to carry out a final treatment with rollers. When installing concrete, this roller work is not necessary. The slip-form paver compacts the material directly inside the machine, using special elements. In order to achieve the desired surface structure of the road, special-purpose machines are often used to work on the material when the slip-form paver has passed over it.

Road Pavers. The actual laying device is a screed. The road paver's screed is swimming on the material, and thus is also called a *swimming screed*. The buoyancy conditions depend on the weight, the screed's angle, the forward speed, and the material's viscosity.

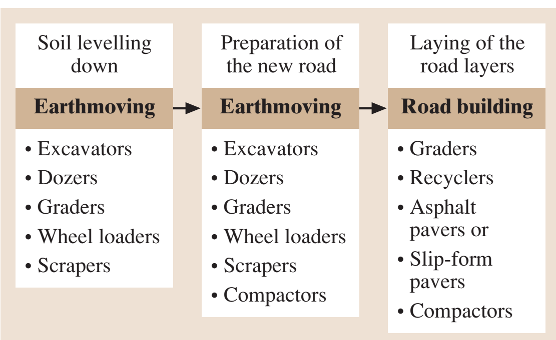

Fig. 14.21 Process chain of road new construction

By means of tension bars, the screed is connected to the vehicle. The connecting spot is situated approximately in the center of the chassis to ensure that the vehicle's pitch does not affect the screed. If the layer thickness is to be changed, one also has to change the height of the linking point of the tension bars. Due to the swimming principle used in these machines, slow material alteration is created, leading to a long-wavelength height variation which is good for driving comfort. Nowadays, steering is exclusively done by electronic leveling systems, which facilitate separate steering of the left and right linkage point of the tension bar.

The screed itself is equipped with additional compaction devices. Using a tamper, the material is stuffed in front of the screed and compacted. For additional density increase, vibration elements or pressure bars used. In order to produce good installation of the hot material, it is necessary to heat the screed's compaction devices that are in contact with the material. This is done by electric systems powered by a generator that is run by a diesel engine. Furthermore gas and liquid heating systems are used for heating the screed using burners. The working width of road pavers is 1–16 m, with deposition layers of up to 0.35 m being possible. Given appropriate material logistics, large road pavers can install more than 1000 t of material per hour [14.21] (Fig. 14.22).

The paver tractor consists of a frame to which the chassis is mounted. Furthermore, it contains the driving unit, consisting of a diesel engine, the gearbox, the cooler, and the hydraulic system. The driver stand is situated in the upper part of the vehicle, giving the driver a good view of the material container and the screed. The chassis is either a wheel or a caterpillar chassis. The caterpillar chassis is composed of two hydrostatically driven chain tracks which are electronically controlled. Apart from steel chains, rubber bands are also often used. The wheel chassis are often triaxial with a large rear-wheel drive and small wheels mounted under the material container. Usually, two axles are driven, but four-wheel drives are also used. The advantage of a wheel chassis is that driving speed of up to 20 km/h are possible, whereas a crawler chassis only permits driving speeds of up to 6 km/h, and caterpillar chassis equipped with rubber belts enable maximum driving speeds of 16 km/h. However, the crawler chassis offers better traction and is less sen-

sitive to soil unevenness, facilitating more even road construction.

In order to meet the requirements of an even layer density and of very even roads, it is necessary to have a regular work process without interruptions. This is only possible with an automotive material reservoir to transport the material from the trucks to the paver in a regulated way [14.23].

In many cases, factors associated with the construction, e.g., too small construction sites, why the paver must work without such a feeder. For this reason, the traction drive as well as all drives for material transport have to be controllable. The command variable of the individual control cycles is the amount of material. In order to measure the amounts of material in the corresponding transport areas, either mechanical material sensors or ultrasound distance sensors are used, with the measured values being processed by digital steering systems.

Compacting the asphalt layer is necessary to ensure its stability. Immediate compaction is carried out by the paver's screed. The following rollers are then used to obtain the final density. The following compaction elements are in use:

- Tampers: The tamper is the first compaction device; it is a tamper bar driven by an excenter shaft. The throw is determined by the excenter radius and can be gradually adjusted. Depending on the material, the throw is about 2–7 mm. Another influencing factor is the drive speed, which ranges from 600 to 2400 rpm.
- Double tampers: Another possibility is to use a double tamper, which is driven by an excenter.
- Vibration stimulator: The majority of screeds make use of the vibration principle in order to compact the layers. Usually, a vibration stimulator is mounted on the blade of the screed, being driven mechanically with an adjustable frequency.
- Pressure bars: Pressure bars are similar to tampers. They are driven by pressure impulses which are transmitted into the layer by the bar, thus effecting compaction.

To meet the required geometrical dimension of the road to be constructed, use is made of leveling systems. Graders, dozers, slip-form pavers, and milling machines are also used, designed to fulfil the following tasks [14.21, 24]:

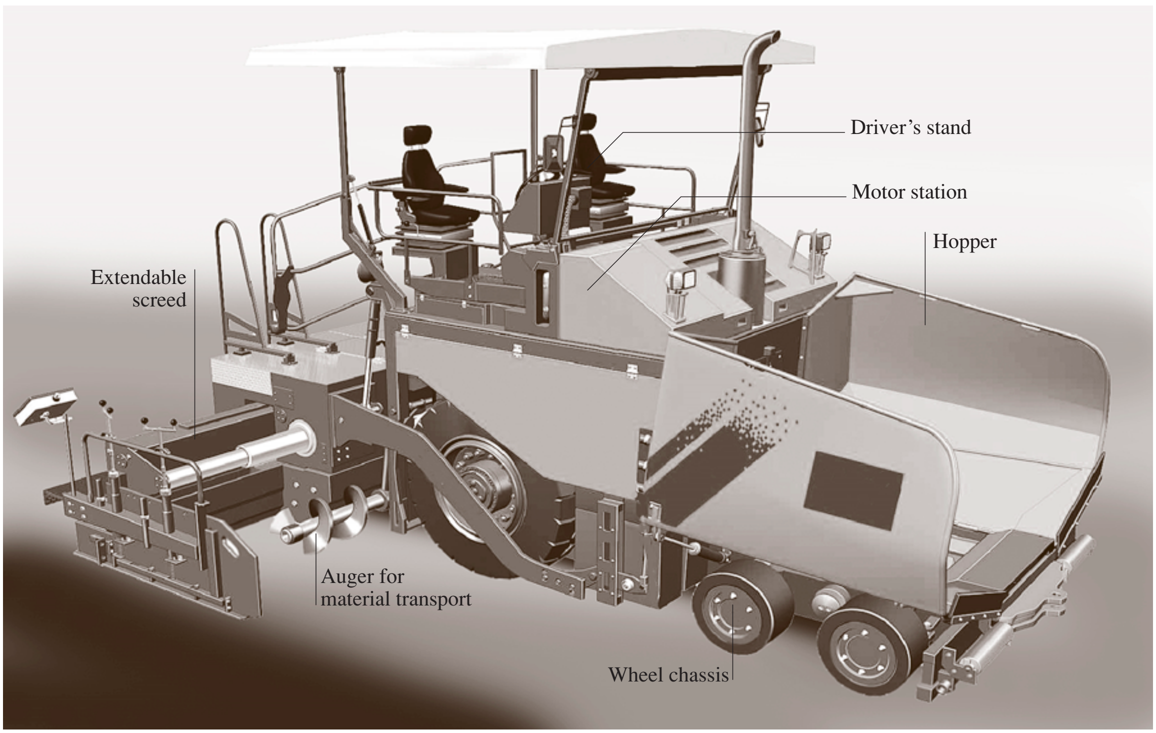

Fig. 14.22 Road pavers

- Position control of the working device
- Height and inclination control of the working device
- Position control of the working device

In the case of road pavers leveling is carried out by height adjustment of the linking points of the tension bar.

Slip-Form Pavers. For concrete road pavement, mainly slip-form pavers are in use today (Fig. 14.23). These machines are characterized by:

- Dragging along the *slipping form*
- Series arrangement of the working devices:
  - To compact the delivered concrete
  - To compact the concrete using vibrators
  - To pave
  - To fix anchors
  - To screed

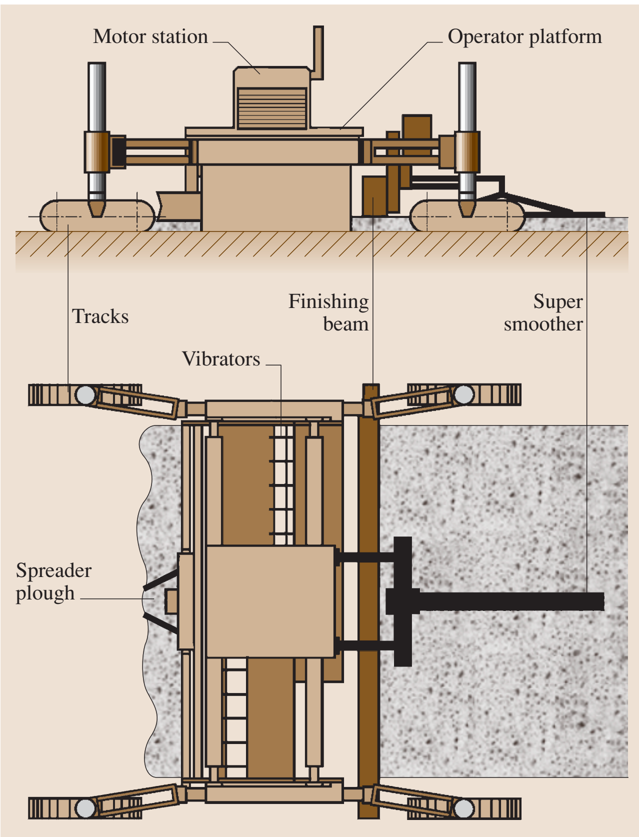

Fig. 14.23 Slip-form paver with variable working widths (after [14.25])

The working devices are connected to the tracklaying chassis in a frame. In contrast to road pavers, leveling in these devices is carried out by lifting and lowering the machine frame. To achieve this, the frame is connected to the tracklaying chassis by hydrostatically driven hydraulic cylinders. Similar to the road pavers, a diesel engine is used for the drive, providing the hydraulic and the electrical system with the energy needed. The installed engine power is about 79 kW in smaller machines, and in larger ones can be up to 300 kW. In smaller machines the chassis consists of three tracks, whereas in larger ones there are four chain tracks. The maximum working width is 16 m, and the layer thickness can be up to 0.45 m [14.21].

Machines Designed for Road Maintenance

Ageing of road materials as well as the weight permanently put on the coating require maintenance measures to be taken in order to ensure the road's function. Machine application depends on the particular road damage and the size of the coat to be worked on. There are five different paving processes [14.26]:

Reshape:	Reshaping of a road layer without new mixing material
Regrip:	Rebuilding of the road grip
Repave:	Rebuilding of a road layer with new mixing material
Remix:	Rebuilding of a road layer with milled and new material
Remix Plus:	Manipulating of the asphalt mixture in combination of rebuilding a road layer

The remix process usually is carried out in situ, i. e., the individual process parts of taking off, mixing, adding new material, laying, and compacting are done in only one stage. Repaving is usually an intermittent process, i. e., after taking off the material (e.g., by cold-milling machines) there is a delayed laying of the material with a paver followed by compaction by rollers.

The focus of the road maintenance process is taking off the damaged material. In the case of asphalt and partially for concrete (Fig. 14.24), this is done by cold milling machines. Here, a diesel engine drives the milling drum using a belt transmission. The milling drum is equipped with cylindric chisels, which serve as cutting instruments, situated in replaceable chisel holders. The roller's equipment as well as the size and the variety of chisels are determined by the application area. In order to avoid dust, the work field is sprayed with water. The removed material is transmit-

ted to a belt conveyor from where it is transported to a truck.

Small milling machines mainly use wheel chassis with three or four wheels. Their working widths are 0.25–1.2 m. Large milling machines, however, offer working widths of up to 2.2 m, with an engine power of about 600 kW. Depending on the machine sizes, milling machines are equipped with wheel or caterpillar tracks which are driven by hydro-motors (Fig. 14.25). The wheels as well as the chain tracks are mounted on lifting cylinders which are connected to the machine's chassis. The milling depth is adjusted by lifting or lowering the machine, controlled by an electronic leveling system.

A machine which is very similar to the milling machine is the recycler (Figs. 14.26, 14.27). It takes off the damaged material and recycles it. Very often various substances or binders such as foamed bitumen, cement or bitumen are added to the material which is to be prepared. Instead of a milling rotor as is used in cold-milling machines, a rotor equipped with cylindric chisels is designed for milling and mixing the milled material with the additional substances.

These vehicles use wheel chassis and tracklaying chassis. Their working widths are up to 3.05 m, working depth is up to 0.5 m, and the installed engine power reaches 500 kW.

The complex processes of in situ road maintenance (shown in Fig. 14.24) requires the machines shown in Fig. 14.27. This machine integrates the work functions of milling, breaking, taking off, mixing and adding new material, spreading, carrying them out in one stage, and precompacting. This helps to save time and reduce traffic obstructions. A machine such as this delivers working widths of 4.2 m.

14.2.5 Farming Equipment

Agriculture's main task is to produce sufficient food to nourish man and farm animals. Since the early Stone Age, when man began to settle and grow plants and animals, people have developed useful devices and

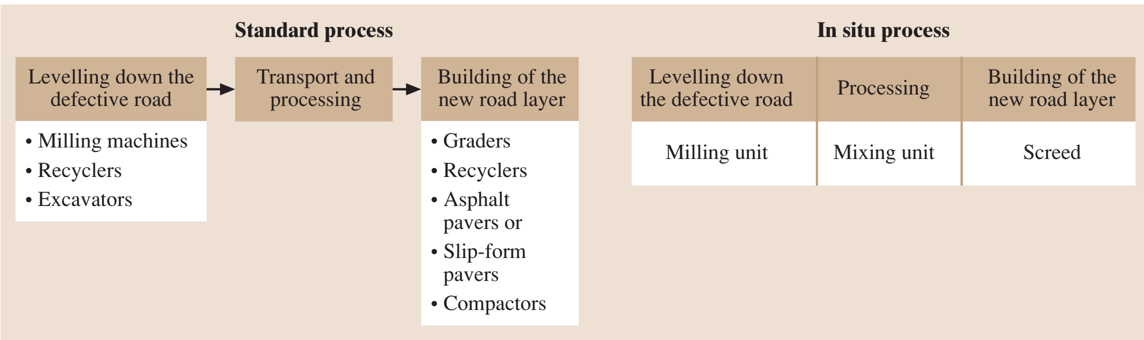

Fig. 14.24 Process chain of road maintenance

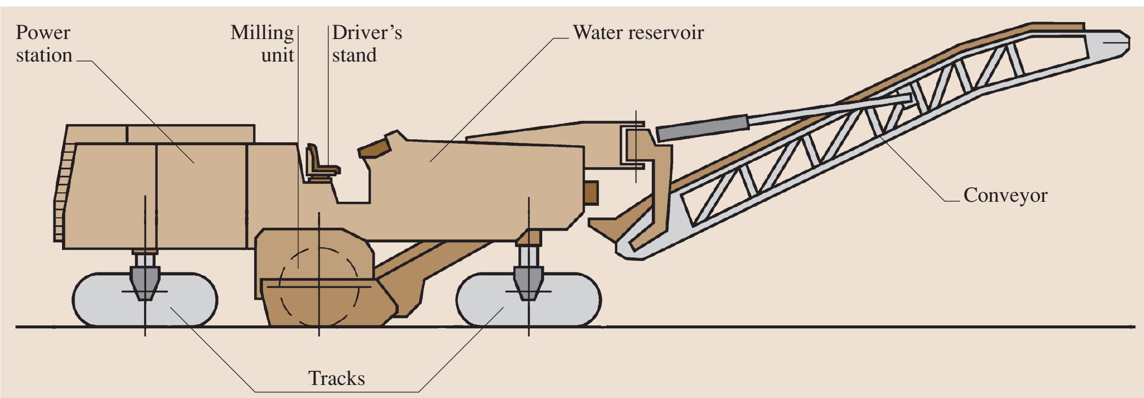

Fig. 14.25 Structure of a cold-milling machine

machines to do the necessary work. Mechanization, however, did not start until the 19th century, when steam engines, which could also drive larger devices such as the steam plough, emerged. Mechanization took a great leap forward in the 1950s when the agricultural sector lost increasing numbers of workers and new production processes were introduced.

The basic tasks of agricultural mechanization are:

- Improving productivity
- Increasing plant and animal yield
- Loss reduction
- Improving work productivity
- Reducing working hours
- Improving work process efficiency
- Improving workers' conditions

These aims lead to greater productivity and reduced resource consumption. Thus, agriculture has the same basic goals as industrial production, but of different goods. The decisive difference is the fact that agriculture is highly dependent on external conditions which cannot be influenced, such as weather and soil conditions. Due to the fact that agriculture is closely related to nature, it is necessary to consider ecological aspects as well.

Classification of Agricultural Machines

In general, agricultural machines are classified into machines used for livestock farming and those used for cultivation. Livestock farming deals with the production of animal products with the corresponding buildings, milking systems, etc. Machines from the mobile working sector are used for outdoor farming, as described in detail below. Due to the large variety of cultivated plants and considerable regional differences, numerous different agricultural production methods and machines have emerged. These machines may be classified as follows:

- *Tillage*: Tillage aims to change soil resources and conditions in order to provide plants with optimum growing conditions.
- *Sowing and planting*: These machines are designed to introduce the seed or the plants into the soil. Due

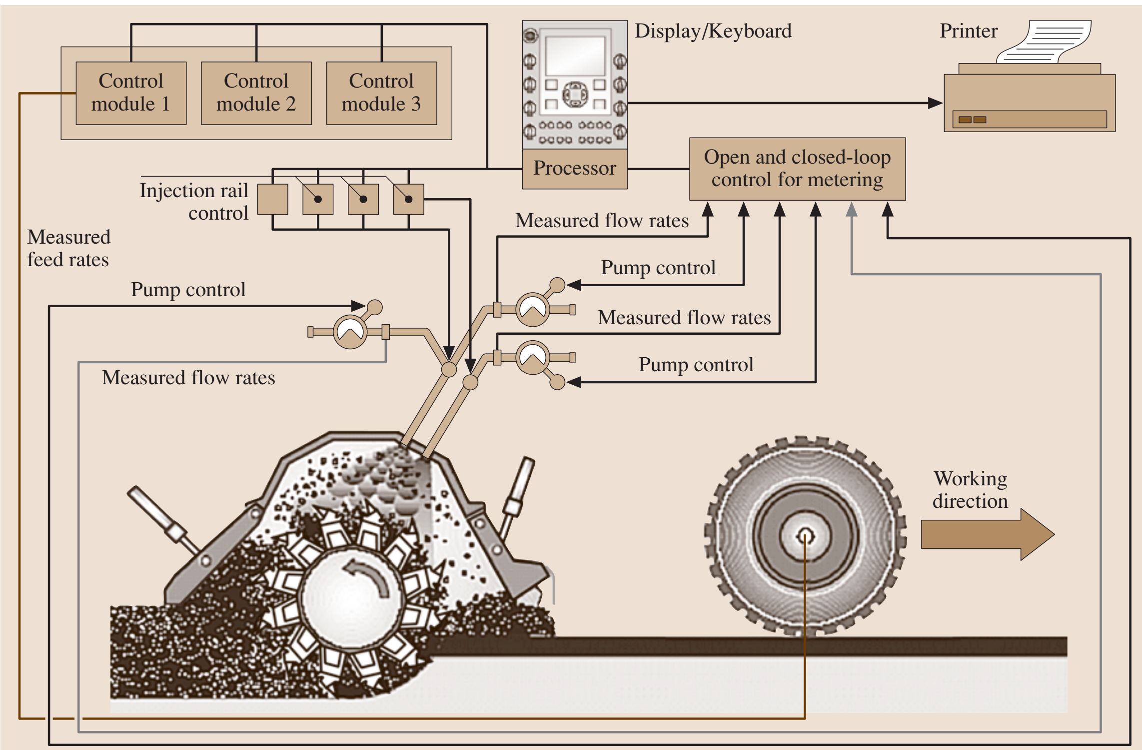

Fig. 14.26 Schematic diagram of the microprocessor control for simultaneous injection of foamed bitumen and water in a recycler (after [14.27])

to the large differences between plants, machine designs vary greatly:

- Drilling machines: Using dose-measuring devices and seed pipes, drilling machines are used to sow seeds. Usually seeds are sown in rows, with their distribution being as regular as possible and continuously adjustable.
- Single-seed drilling machine: This machine lays a single seed at a particular soil location. This is necessary, e.g., with corn and sugar beets, which need to be planted at a specified separation to ensure successful growth.
- Planting machine: These are special machines designed to lay tubers, e.g., potatoes, into the seed bed. They should fulfil the following requirements: regular, constant planting depth, exact tuber distance even with different tuber sizes and shapes, and regular row distance with even soil covering of the tubers.
- Transplanters: They are for plants, e.g., trees or certain sorts of vegetable.

• *Fertilizing*: Fertilizing machines are designed to distribute fertilizers regularly onto fields. There are two main groups of fertilizers:
  - Organic fertilizers (e.g., solid and fluid manure)
  - Mineral fertilizers

• *Plant protection*: The aim of plant protection is to protect crop plants against damage effected by weeds, fungi, and diseases. To achieve this, various methods are employed:
  - Physical-mechanical methods
  - Chemical methods
  - Biological methods

Mechanical plant protection removes weeds mechanically. Chemical and biological plant protection make use of plant-protecting agents. The machines used for this purpose are sprayers that mix fluid plant-protection agents and distribute them by using a hydraulic pump system equipped with spray valves. Modern sensor systems are able to identify damaged plants so that the agents can be distributed as required. Fruit culture and viniculture additionally make use of vaporizers, which – in contrast to sprayers – use air to support the drop transport.

• *Crop harvesting*: The majority of agricultural goods are crops such as grasses or cereals. Harvesting these culture plants means mowing their stems. The cutting method depends on several factors, the most important of which are:
  - Crop humidity
  - Crop geometry and stability
  - Harvest aim

After the cutting process, the crop is further processed. In the case of grass, conditioners are used to destroy the external blade strata in order to cause the humidity to leave the plants faster, thus accelerating the drying process. Hay treatment machines are used to turn the grass so that it dries faster. They are additionally used to gather the crop into swaths so that a forage harvester or compactor can pick it up subsequently. It is the compactor's task to compact the crop, thus reducing its transport volume. Crop choppers are designed to chop the material so that it can be processed to become silage.

• *Grain harvesting*: Grain is one of the most important agricultural plant to be cultivated; it is

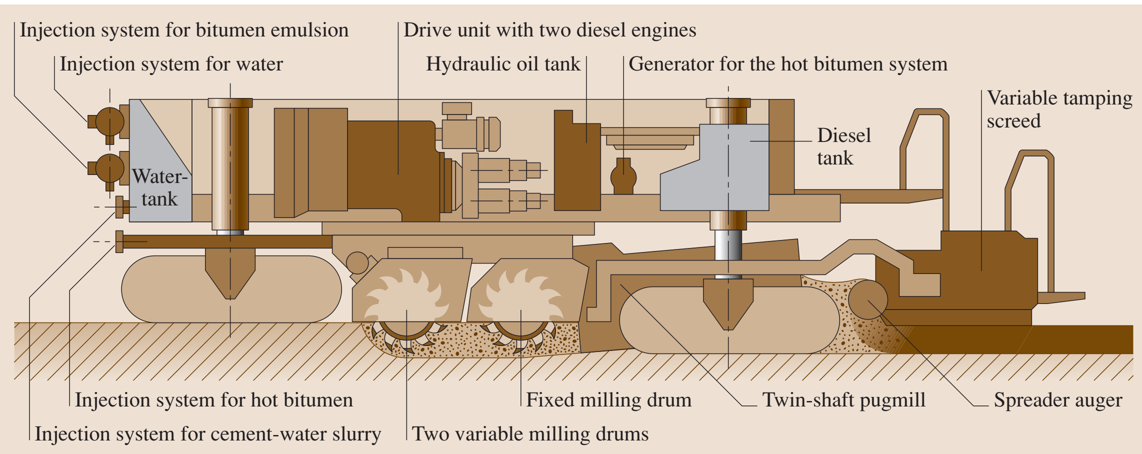

Fig. 14.27 Configuration of an in situ recycler (after [14.27])

harvested by combine harvesters. These machines are extremely complex, applying several mechanical process technology features:
– Cutting stems and ears
– Conveying stems and ears
– Threshing
– Separating grains from straw
– Cleaning
– Temporary crop storage
– Chopping straw

- *Root crop harvesting*: Potatoes and sugar beets are among the most important root crops. Harvesting them involves digging the crops out of the soil, cleaning, and then transporting them from the field. In terms of complexity, machines for this purpose can be compared to combine harvesters.
- *Engineering for intensive cropping*: The machines used for this task are special-purpose machines such as cotton harvesters or grapes harvesters.

Tractors

In the area of agriculture, tractors are of special importance as half of all agricultural machine investment is for tractors [14.9]. The tractor's tasks are [14.10]:

- Traction work on the field
- Transport work on the farm
- Driving mobile and stationary machines and devices
- Working with mounted devices

Figure 14.28 shows the most important tractor constructions. Most of the tractors used today are standard tractors. If one looks at the specified construction types, the universal tractor (standard tractor), equipped with a comfortable cabin and four-wheel drive, is of central importance. The huge range of different tractor concepts is reflected in the installed engine power capacity, which may vary from a few to several hundred kW.

Frames

The frame is the actual undercarriage of mobile working machines. In the case of tractors, the function of carrying is partially integrated in key components such as engine, gears, and axles so that there are different construction types:

- Block construction or frameless construction: This is the prevailing construction type used in standard tractors. Its characteristic feature is the link of axles, gears, and engine by means of flanges. The cases of these components are usually self-supporting cast constructions.
- Partial frame construction: This is a combination of block and frame construction, with various possible configurations. Here, the engine and the front axle are usually mounted on a steel frame. The gears and the rear axle, however, are still constructed as self-supporting components. In the case of the so-called *three-fourth frame*, only the rear axle is a self-supporting construction.

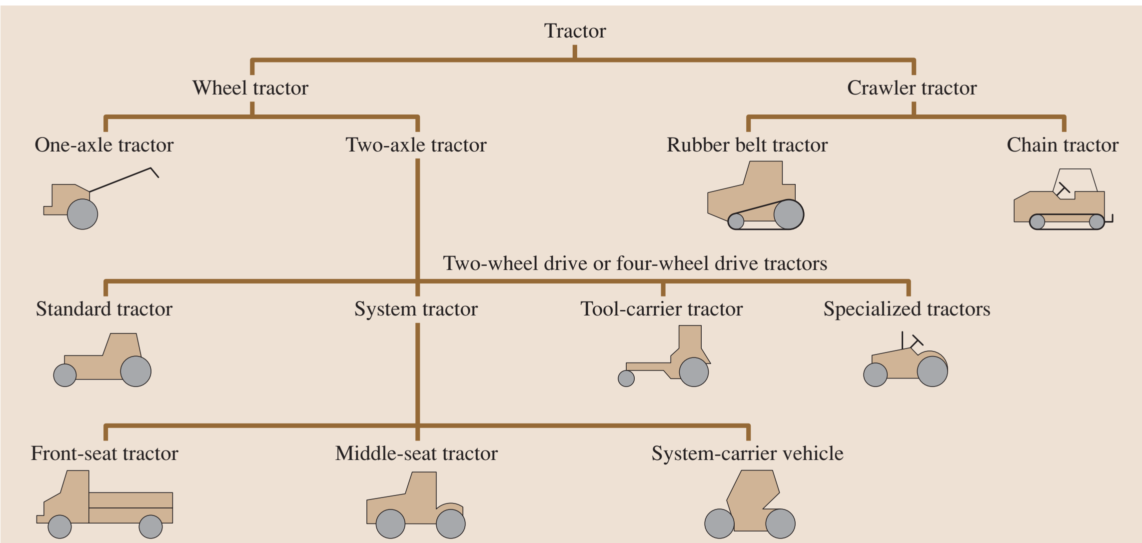

Fig. 14.28 Systematic classification of tractors (after [14.10, 28])

- Full-frame construction: Here the frame has to completely fulfil the task of the chassis. This approach is mostly used in machines with a small number of pieces, in system tractors, and in machines with a large range of engine and gear variants.

Chassis and Axles

In modern tractors, it is possible to drive all axles; pure rear-axle drives are the exception rather than the rule. The advantages of the four-wheel drive are:

- Larger traction force for field work (up to about 40% more for a traction weight increase of only 20%)
- Increased traction capacity, with equal slip and engine use
- Reduced energy consumption relative to tractive capacity
- Improved work with front devices, such as frontend mowers
- Improved driving safety
- Soil protection
- Smaller rear wheels
- Cost-saving front wheel brake

The disadvantages of the four-wheel drive are:

- Higher costs for the same engine capacity
- Greater losses, even with passive four-wheel drive
- Increased maintenance standards
- Larger turning circle

In the case of tractors, suspension and damping of the vehicle is done completely by the tyres. Due to the increased speed of standard tractors, up to 40–50 km/h, the suspension of the machine is of growing importance. As the rear axles are rigid, except for in a few exceptions, standard tractors are equipped with suspended front axles. Much use is now made of front-axle suspension with rigid axles, height control, and the possibility of locking the suspension for frontend loader work [14.29].

Power Transmissions

Tractors mainly use diesel engines due to their lower fuel consumption. This is achieved by direct diesel injection and the engine being charged by an exhaust gas turbocharger and air cooling. Over the last few years, there has been increased use of electronic engine controllers, facilitating directed control of the injected fuel and the injection time, which again helps to increase the engine capacity. Furthermore, it is necessary to combine modern injection systems and charging systems in order to keep in line with stricter exhaust gas regulations.

Tractor engine development is very closely related to that of other commercial vehicles today. The tractor's frameless construction impeded the use of standard engines whose case constructions could not take up the loads that would have been necessary for block construction. Meanwhile many tractors have a frame construction, easing this restriction.

Due to the complexity of the drive – the power take-off (p.t.o.) drive and four-wheel drive – a tractor's transmission makes production very complex. It is the gears' main task to adjust the tractor's driving speed to the individual working conditions. The tractor's rated power can only be transmitted with the rated torque. Therefore, the drive wheels' torque has to be adjusted in order to transmit the desired power capacity. Further tasks of the gears are changing the driving direction and driving auxiliary drives (p.t.o., four-wheel drive, frontend mower).

In standard tractors, the basic construction of the gears has been influenced by the frameless construction for a long time (Fig. 14.29). However, in recent

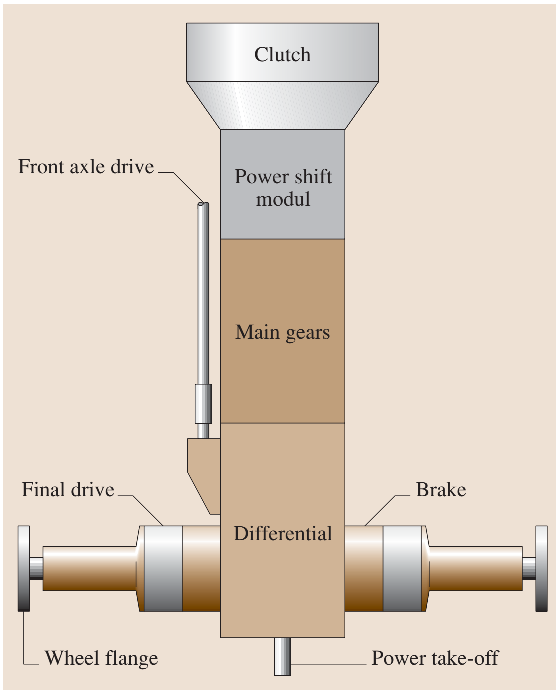

Fig. 14.29 Widespread arrangement of the most important functional groups in tractor gears of the main work pieces area (after [14.9])

years a tendency towards using frame constructions has emerged.

The engine transmits the power to the gears through the driving coupling and p.t.o. coupling. After fruitless attempts to establish direct conventional transmission in standard tractors until recent years, engineers mainly worked on power-shifted transmissions. Gear-shifted transmissions are often constructed according the so-called *group principle*. This variety of construction saves both gears and time. Due to the multiplication effect, a maximum of eight wheel pairs are needed; e.g., 16 forward steps with four basic gears and four groups. In practice, the groups are arranged in order to provide the driver with favorable work speeds (e.g., one field group "L" and one road group "H").

The latest result of tractor development is the continuously variable transmission. The advantages of this concept are good driver comfort, wide spread speeds, good efficiency, and flexible distribution of the load to the drive and p.t.o. In a continuously variable transmission, the power from the diesel engine is distributed by a planetary gear to a mechanical and a hydrostatic gear unit. Before leaving the gears, the changed power parts are added again. This results in good use of the mechanical drive's high efficiency as well as of the hydrostatic drive's shifted work process.

Figure 14.30 shows the basic construction of a tractor's continuously variable transmission using two gears. Due to the mechanical two gear transmission, which is applied only in the standard tractor, there are two driving speeds: 0–32 km/h and 0–50 km/h.

It is an important task of tractors to supply power to drive working devices. Apart from the p.t.o. delivering the mechanical power, tractors also supply hydraulic power. On the one hand, the latter is needed for driving working machines; on the other hand, hydraulics are also used to drive the hitch. Hydraulic systems for tractors have gained in importance. Today, there are two main tractor hydraulic systems to be distinguished in their basic construction:

- *Constant-flow system*. These simple hydraulic systems mainly use gear wheel pumps. The system's pressure depends on the required load, with the maximum pressure being determined by a pressure restriction valve. When a wheel gear pump is used, volume flow inside the system is only possible by varying the pump's rotation speed. The striking advantage of this system is its low cost. The disadvantage of these systems is that, if several devices are consuming power, they will influence one another. Furthermore, it is always the consumer with the smallest load that is supplied first. Another disadvantage is that the part of the volume flow that is not needed by a consumer has to be throttled away, which results in considerable losses. Modern constant-flow systems use multicycle systems running different consumers independently from one another by using separate pumps.
- *Load-sensing systems*. These are the modern hydraulic systems used in tractors, making use of axial piston displacement pumps. They allow continuous adjustment of the volume flow. A characteristic feature of a load-sensing system is that the volume flow is adjusted by a valve depending on a pressure drop. With the valve closed, only a small volume flow is provided to maintain a pressure of 2–3 MPa. When a valve is opened, the load pressure increases and is transmitted to the displacement pump's control by means of load pressure re-registration. The volume flow controller shifts the pump to a higher volume, thus keeping the pressure flow through the valve at a constant rate. The advantage of this system is that several power consumers can be supplied simultaneously with oil by one pump.

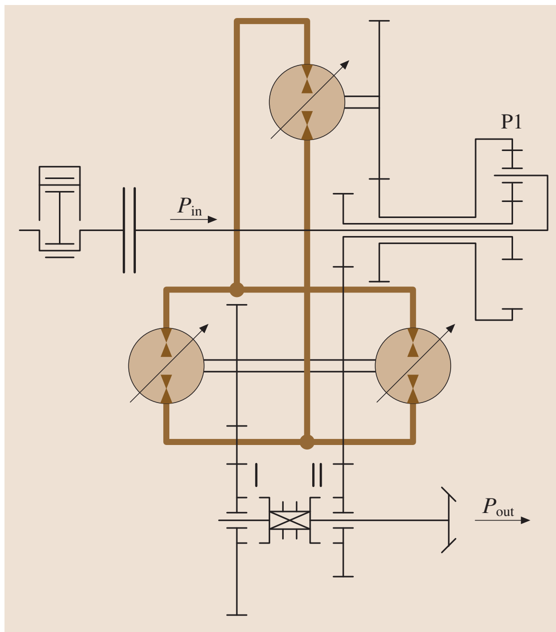

Fig. 14.30 Structure of the continuously variable transmission (after [14.30])

Operation Elements

It is only in combination with work devices that a tractor becomes a working machine. These devices may be attached, hitched, or mounted to the tractor. For rear device attachment, a three-bar linkage combined with a power lift has proved to be useful for the following reasons:

- Statically defined rigid connection between tractor and device
- Adjustable device due to the power lift
- The three-bar linkage can be adjusted to different devices by control devices
- The possibility of lateral mobility restriction or height and lateral mobility restriction

The three-bar linkage consists of two lower links and one upper link. The three-bar linkage's individual part dimensions are standardized into four categories (I–IV) for different power classes [14.31].

For a long time, rear hitches have been equipped with a control device that automatically lifts and lowers the power lift depending on a control value. By means of this power lift control, the driver is relieved of a task and working efficiency is increased by reducing the slip between the tyre and the soil as well as by raising the drive force. Possible control values are the device position relative to the tractor (position control), the traction force acting between the tractor and the device (traction force control), the device position related to the soil (depth control), and a mixture of traction force and position control (mixed control).

When using slip control, the actual driving speed is measured by a radar sensor. The theoretical speed is defined by a wheel-speed sensor. The electronics determines the speed difference and the slip. If the speed difference is smaller than a fixed limit, the electronic lifting control only works with traction force control. If the speed difference exceeds this limit, the traction force is changed by working depth modification so as to reduce the working depth and the slip. Another function of the electronic lifting control is active vibration removal, which involves balancing of the device's vibrations when passing on roads by means of automatic hydraulic steering in the opposite direction. This helps to improve driving comfort and steering conditions when driving with heavy devices attached to the tractor. The force-measuring bolts of the lower links serve to measure the force signal of the lifted device. The dynamic part emerged by vibrations is used as an actual value for lifting device control. In a restricted control area, for damping the lifting device is lifted or lowered slightly together with the attached device.

Control System and Electronics

The task of electronics is to control a tractor's components [14.32]:

- Motor
- Engine
- Hydraulics
- Gears
- Devices
- Data collection and storage
- Diagnosis

Modern tractors mainly use microcontrollers [14.26] (Fig. 14.31), equipped with CAN interfaces for communication. This yields new possibilities of diagnosis and overall optimization of the tractor's system. Due to the fact that tractors are applied with very different devices attached, which also using electronic control systems, it is important to make them communicate by a uniform interface, e.g., according to the ISO 11783 standard [14.33].

14.3 Machinery for Concrete Works

14.3.1 Concrete Mixing Plants

Since they must be well suited to their intended use and to construction needs, concrete mixing plants form a class of machinery with highly diverse designs. The diversity of concrete mixing plants' design features is connected with their capacity (10–250 m^3/h), their compatibility with the means of receiving the produced concrete mix, the production process control automation, the need for printing certificates for the sold concrete mix, the required assembly area, and the climatic conditions in which they are operated.

Concrete mixing plants can be classified as follows [14.34]:

- Concrete mixing plants (equipped with a mixer) producing ready-made concrete mix and concrete mix batching plants for proportioning and feeding

concrete mix constituents into truck mixers. Both kinds of plants can be built in vertical (tower concrete mixing plants) or horizontal configuration. Concrete mix batching plants may feed, depending on the time needed for transporting concrete mix to the destination, only dry constituents (aggregate and cement) or aggregate, cement, and water into truck concrete mixers.

- Stationary, transferable, and mobile concrete mixing plants. The kind of concrete mixing plant is determined by the operating costs, dependent on the length of time of operation at a given location.
- Continuous and batch production concrete mixing plants. Batch production concrete mixing plants are used on sites where the produced concrete

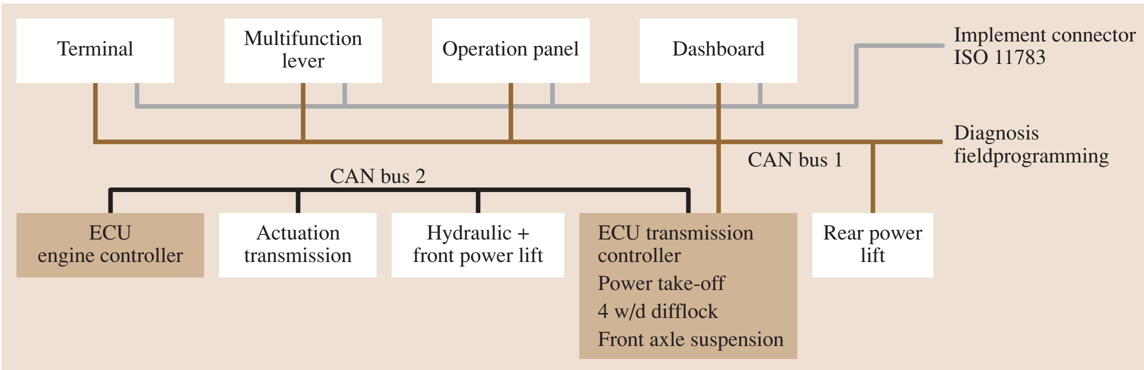

Fig. 14.31 Structure of a tractor control system

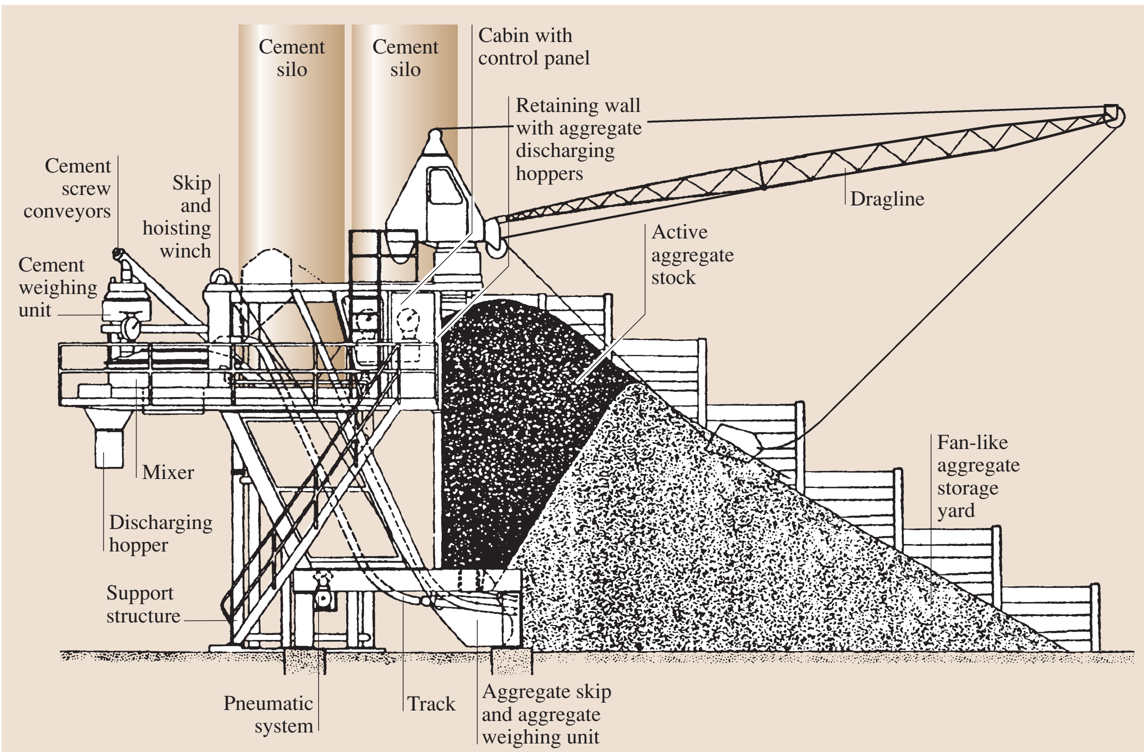

Fig. 14.32 Horizontal concrete mixing plant

mix's composition often needs to be changed, while continuous production mixing plants are used on construction sites which require large quantities of homogenous concrete, such as dams or airfields. Schematics of two basic types of batch production concrete mixing plants – horizontal and vertical (tower) – are shown in Figs. 14.32 and 14.33.

The concrete mixing plant's working cycle begins with the filling of the proportioners with aggregate, cement, water (if the latter is dosed by a weighing unit), and admixtures, which are then fed in the appropriate order into the mixer.

If flow-type water dosage units are used, water is fed into the mixer after the dry constituents have been charged into it. When the mixing process ends, the contents of the mixer is discharged into the recipient. Modern concrete mixing plants perform 50–60 working cycles per hour.

In order to achieve the desired technological capacities, the pressure of the water with which the concrete mix plant is supplied should be 0.4–0.6 MPa. The active aggregate stock (Fig. 14.32) represents the free-falling amount of aggregate which can be fed into the skip without using the dragline. The concrete mixing plant's personnel usually consists of two operators (operating the concrete mixing plant and the dragline). Nowadays automatically controlled charging skip hoists are increasingly being employed, allowing the operating personnel to be reduced to one person.

Because of their technological and economic advantages, horizontal concrete mixing plants are most commonly used in the construction industry.

The other type, vertical concrete mixing plants (Fig. 14.33), is characterized by the location of aggregate storage bins above the mixer. In vertical concrete mixing plants aggregate is usually transported to the storage bins by belt or bucket conveyors.

Because of the considerable height of vertical concrete mixing plants and the weight of their supporting structures they are constructed as stationary facilities within prefabricated concrete plants and as readymix concrete mixing plants for permanent locations. Their advantages include the ease of fitting them into concrete products manufacturing plants and adapting for concrete mix loading into overhead trolleys as well as easier adaptation to operation at low ambient temperatures. As a rule they are built for year-round operation.

Mainly electric motors are used in the power transmission systems of concrete mixing plants.

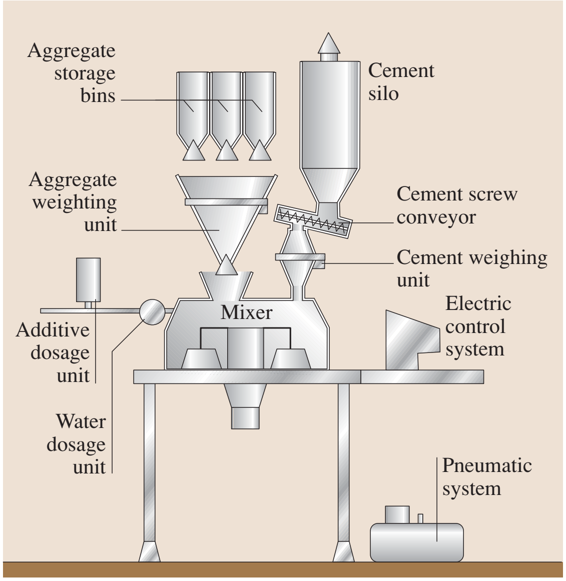

Fig. 14.33 Schematic of vertical concrete mixing plant

Only the closing of the devices batching concrete mix components is effected by pneumatic actuators because of the high speed of motion required.

Since it is capable of generating great forces, a hydraulic drive is usually used to open and close the mixer's discharging gate.

The most popular type of concrete mixing plant appears to be the transferable horizontal concrete mixing plant, which is characterized by a simple design and that lends itself to quick assembly on the construction site. The components of horizontal concrete mixing plants are transported to the site on generally available means of road transport. Concrete mixing plants specially designed for quick relocation are referred to as mobile. They are usually mounted on specially designed trailers.

Concrete mixing plants are usually built according to the needs of the individual user, who can choose the kind of mix, the height at which the concrete mix is discharged, the kind of aggregate storage facility (Fig. 14.34), the number of aggregate fractions and grades of cement, the batchers' weighing systems, the use of admixture and additive proportioners, the automatic make-up water dosage unit, the type of control system, the operator's cabin, adaptation to operation at low temperatures, and environmental compatibility.

Depending on the size of the concrete mixing plant, users can choose from simple concrete mix batcher weighing units with a spring head with an accuracy of ±0.5% or electronic ones based on strain gauges whose

accuracy, according to some manufacturer's specifications, is as high as ±0.1%.

An additional advantage of weighing units based on strain gauges is that the signals can be processed directly, whereas in older systems the weighing head indicator rotation had to be converted into an electric signal by means of coupled voltmeters or reed relays mounted on the head's dial.

The use of make-up water dosage devices which take aggregate moisture into account is essential when high concrete homogeneity is required.

Automatic make-up water dosing devices which take aggregate moisture into account can be divided into two groups:

- Devices determining the water content in aggregate (chiefly sand) and adjusting on this basis the amount of water fed into the mixer. The water content is determined by gauges, built in at the outlet from the sand storage bins, measuring electric conductivity, microwave flow, permittivity or the moderation of fast neutrons.
- Devices dosing water to the concrete mix on the basis of concrete mix consistency determinations. The consistency is determined by measuring the electrical resistance of the concrete mix. Gauges built into the mixer's bottom or electrodes mounted similarly as mixing blades are used for this purpose.

State-of-the-art systems for controlling the production process in the concrete mixing plant are available to order.

The application of personal computers (PCs) and programmable logic controllers (PLCs) represents a revolution in concrete mixing plant control systems, making it possible to use any number of recipes, produce batches constituting any percentage of the nominal batch of concrete, choose the number of batches, transfer data remotely to program recipes, print certificates for the manufactured concrete mixes, and accurately control concrete mix inventories and sales.

Contemporary concrete mixing plants must meet environmental requirements, firstly air protection requirements. This is ensured by sealing off (with closing flaps and dust filters) the mixers as they are filled with dry components and using efficient air–cement mixture filters in the cement silos. Also the concrete mix residues from washing the mixer must be utilized.

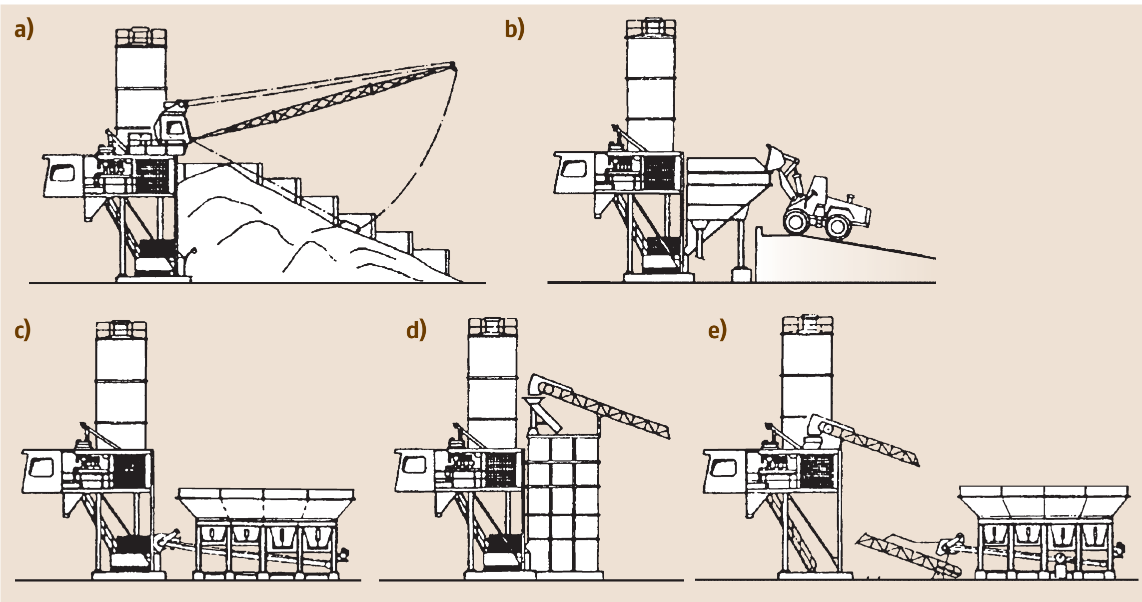

Fig. 14.34a–e Different aggregate storage solutions **(a)** Fan-like storage yard. **(b)** Fan-like storage bin with loading ramp for loader. **(c)** Row aggregate storage bins situated by concrete mixing plant, and belt conveyor. **(d)** Fan-like storage bin with aggregate distributor and belt conveyor. **(e)** Row aggregate bins with belt conveyor weighing and feeding aggregate into container located above mixer

14.3.2 Concrete Mixers

According to the definition given in [14.34], the concrete mixer is a machine designed for the production of concrete mix by mixing measured (by mass or volume) proportions of water, cement, aggregate, and chemical additives (if used) within a certain time limit. Depending on its design, the concrete mixer consists of a basic unit, called a mixer, and ancillary units such as: a wheeled supporting frame or a support structure, a charging skip (possibly with a weighing device) for transporting concrete mix components, a water dosage unit, a mechanical shovel, and a control box.

Concrete mixers form the largest group of construction machines. One can find them on nearly each construction site. They are highly diverse as regards size, which is defined in terms of dry component capacity or the volume of ready concrete obtained from one batch [14.35], and design.

There are concrete mixers with a dry components capacity of 50–12 000 l. Small concrete mixers with a capacity of 50–250 l usually work as single machines with manual transport of concrete mix components to the mixer. In order to use their potential rationally, concrete mixers with a capacity above 375 l should work in conjunction with mechanized concrete mix components transport, i.e., they should be incorporated into a concrete mixing plant.

Depending on the way they operate, concrete mixers can be classified as follows:

- Freefall (gravity) concrete mixers versus compulsory concrete mixers
- Batch- versus continuous-type concrete mixers.

Freefall mixers find application in monolithic construction for production concrete mixes with consistency ranging from liquid to plastic. They are usually used for the construction of residential buildings and livestock and public utility structures. Depending on their discharging method, three types of freefall mixers can be identified: tipping-drum concrete mixers, reversing-drum concrete mixers, and discharging chute concrete mixers. Tipping-drum concrete mixers with a dry components capacity of 50–250 dm^3, used for the production of concretes and mortars in family housing, form the most numerous group among gravity mixers (Fig. 14.35). Similarly as for electrical appliances, they are distributed by chain stores. The main hazard associated with their use is the possibility of electric shock. This hazard can be eliminated through the use of an integrated double-insulated motor switch unit.

To facilitate their transport on public roads concrete mixers can be fitted with towbars with a hook coupling, pneumatic tyres, a brake, and lights.

For more thorough washing after work the mixing drum is closed with a special cover so it can be rotated horizontally.

Tipping-drum freefall concrete mixers have a capacity of 350–1000 dm^3, whereas reversing-drum concrete mixers typically have a capacity of 350–1000 dm^3. Discharging chute concrete mixers are being phased out and replaced by mixers of the above two types. Their design used to be advantageous when combustion engines with one sense of rotation were employed to drive them whereby reversing gears did not have to be used. As electric drives have been widely introduced and the production of concrete mix could be automated, their design became obsolete.

Current development of freefall concrete mixers is directed towards improving their operational safety conditions, reducing noise emission, and facilitating their transport on public roads and maintenance.

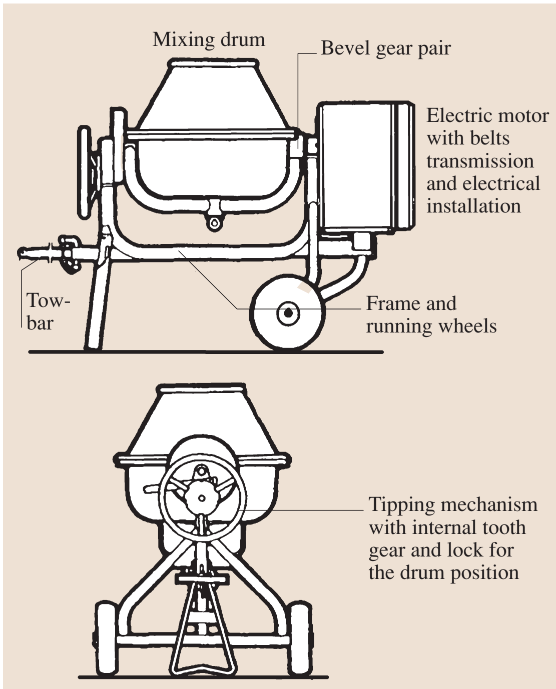

Fig. 14.35 Small-sized tipping-drum gravity concrete mixer equipped with traveling wheels

Compulsory concrete mixers are used for the production of all types of concrete mixes and, from the concrete preparation technology point of view, their application is unlimited.

Compulsory concrete mixers are divided into two classes: pan-type and paddle-type (trough-type) concrete mixers.

In pan-type concrete mixers, mixing is effected by the rotation of a set of agitators inside a pan with a vertical axle, whereas in paddle concrete mixers the set of agitators revolves in a trough with a horizontal axle.

Within the class of pan-type concrete mixers six types of machines can be identified: turbo concrete mixers, planetary concrete mixers, turbo planetary concrete mixers, countercurrent operation concrete mixers, concurrent operation concrete mixers, and concrete mixers with a high-speed stirrer. In the present-day construction industry and the concrete prefabrication industry the first three types of concrete mixers, i. e., turbo concrete mixers, planetary concrete mixers, and turbo planetary concrete mixers, are the most commonly used. The operation of these machines' agitators is illustrated in Fig. 14.36.

A planetary concrete mixer with a capacity of 1000 dm^3 is shown in Fig. 14.37.

As already mentioned, turbo concrete mixers, planetary concrete mixers, turbo planetary concrete mixers, and one- and two-agitator paddle mixers are the most popular types amongst the numerous group of compulsory concrete mixers. No clear advantage in terms of the quality of the produced concrete mixes of a single concrete mixer type over the other types is observed for ordinary concretes [14.35]. As regards special concretes (e.g., with a very low water/cement (W/C) ratio, extreme consistencies or made using non-mineral aggregates) the application of a particular type of concrete mixer should be agreed on between the purchaser and the manufacturer. When purchasing a concrete mixer one should also take into consideration the particular features of each concrete mixer type, such as:

- The possibility of using large-size coarse aggregates: concrete mixers with elastically suspended mixing blade arms are better suited for this purpose than those with rigid suspension of the mixing blade arms.
- The power demands of the mixing process: one can assume that the power demands for the mixing process in a planetary concrete mixer will be lower (by about 25%) than that of a turbo concrete mixer.
- Environmental compatibility: the design of the upper cover of the mixer should protect the environment against cement dust emission and concrete mix splashing, and the seal of the discharge gate should prevent concrete mix leakage.

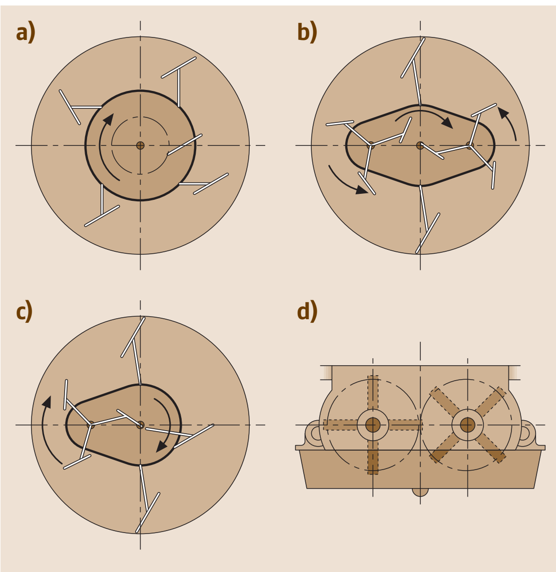

Fig. 14.36a–d Schematics illustrating operation of selected types of pan-type concrete mixers and two-agitator paddle concrete mixer

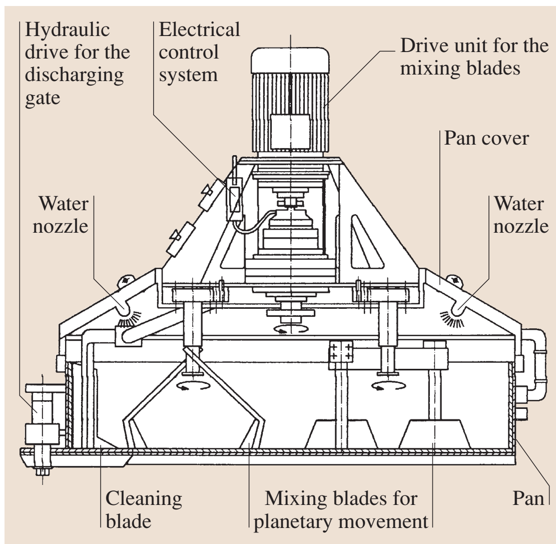

Fig. 14.37 Planetary mixer with a capacity of 1000 dm^3

- Protection against agitator drive system overload: the use of hydraulic torque converters prevents drive system overloads and ensures a smooth start of the rotation of the agitators as the mixer is filled; also elastic suspension of the mixing blade arms protects the drive against overloading and deformation of the mixing blade arms.
- Quick distribution of make-up water in the mass of dry components to reduce mixing time: several suitably arranged water nozzles ensure that the concrete mix quickly becomes homogenous.
- The concrete mixer's dimensions should be suitable for transport on public roads.
- The use of abrasion-resistant materials for the blades and the linings.

14.3.3 Truck Concrete Mixers

The truck mixer (Fig. 14.38) is designed for producing homogenous concrete mix and transporting it over long distances. It consists of a pear-shaped drum (usually a freefall, reversing one) inclined at an angle of 15° and a self-propelled chassis or a trailer. Its accessories include: a water tank, a water dosage unit, a charging hopper, and discharging chutes. The drum is supported by a cylindrical pin on the drive side and by two rollers mating with a rigid ring fastened on the drum. As concrete mix components are loaded into the drum and mixed, the drum revolves in one direction. During discharging the drum revolves in the opposite direction.

It is required that the mixing drum can rotate at several rotational speeds: at the highest speed while being filled or emptied (e.g., into a concrete pump), at a lower speed during mixing, and at the lowest speed during travel. For this reason a hydraulic drive is most commonly used for rotating the drum. This drive enables stepless change of the drum's revolutions in a range of 0–14 rpm in both directions. This ensures the most suitable mixing drum revolution rate for concrete mix loading, transport, and unloading, adjusted to concrete mix placement on the construction site. The truck mixer's hydraulic drive powered by the vehicle's engine is shown schematically in Fig. 14.39. It consists of a combustion engine, a hydraulic pump with an adjustable rate of delivery, a hydraulic engine, and a planetary gear to drive the mixing drum. The prime mover of the mixing drum in truck mixers can be an independent combustion engine or the engine that propels the chassis.

The factor limiting the distance over which concrete mix can be transported by truck concrete mixers is the setting time, determined mainly by the ambient temperature and the temperature of the concrete mix. If the expected transporting time is longer than the setting

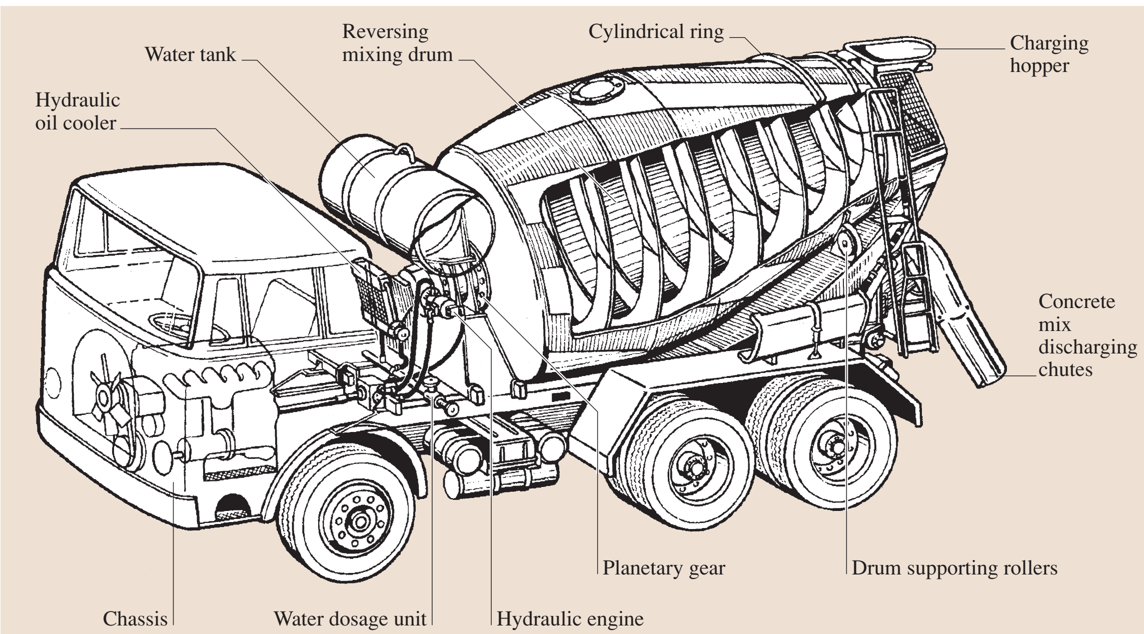

Fig. 14.38 Truck mixer with drum driven by the truck's engine

time, dry components are fed into the concrete mixer and, 35 min before discharge, water is added and mixing is started.

While the truck concrete mixer filled with both concrete mix and dry components is traveling the contents is mixed at a low rate (about 3 rpm) in order to prevent concrete mix segregation or cement setting in contact with moist aggregate.

The following trends in the development of truck concrete mixers can be observed:

- The use of mixing drums with an ever greater capacity – 9, 10, and 12 m^3 – aimed at reducing transport costs and making it easier to maintain continuity of concreting when erecting large concrete structures. In order to increase the load capacity of concrete mixers they are fitted out with an additional rotary axle at the back of the truck, which is raised during discharging and while driving without a load.
- The combination of a truck concrete mixer and a concrete pump with a distributing boom or a belt conveyor for direct placement of the concrete mix on small construction sites;
- The adaptation of the truck concrete mixer for concrete mix transport at low temperatures (as low as −60 °C). In this case, the mixing drum is made of two shells (an outer shell and an inner shell) and hot exhaust gas is fed into the space between the shells.

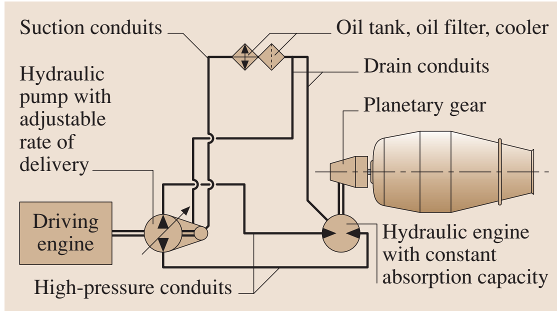

Fig. 14.39 Schematic of a truck mixer drum's hydraulic drive powered by the truck's engine

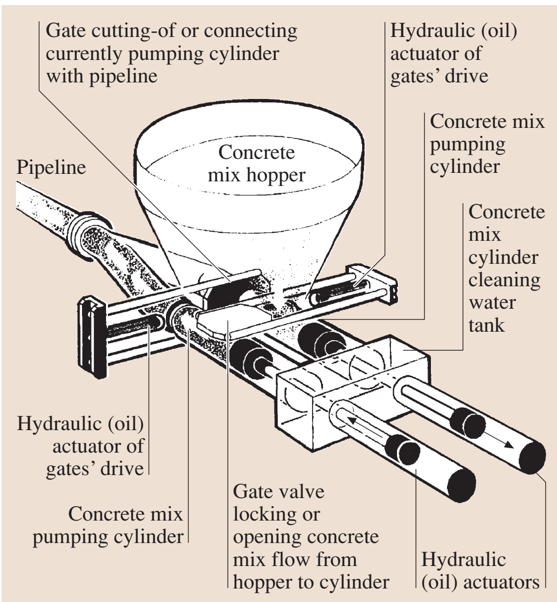

Fig. 14.40 Principle of operation of a concrete pump with control valves in the form of flat gates with connecting ports

14.3.4 Concrete Pumps

Concrete pumps have become the dominant means of concrete mix conveyance on the construction site. They have entirely supplanted pneumatic feeders, which deliver concrete mix in batches. The rapid development of concrete pumps started once hydraulic drives were incorporated into their design, supplanting crank power drives.

Another breakthrough in the development of concrete pumps was the use of distributing booms, which greatly facilitated the placement of of concrete in the work area by delivering concrete mix directly to the placement area and distributing it there.

Currently the most common pump design is a pump with two parallel, alternately operating concrete mix cylinders whose pistons are driven by hydraulic (oil) actuators connected to them in series (Fig. 14.40).

The reciprocating motion of the concrete mix pistons is controlled by means of two noncontact limit switches located in the cleaning water tank. Switches of the same type are also used to control the motion of the cutoff valves.

An important distinguishing feature of particular piston-type concrete pump designs is the system of valves that controls the flow of concrete mix from the hopper to the cylinders and from the cylinders to the conveying pipe.

Besides valves in the form of flat gates, other valve systems, such as the conveying pipe's swing segment (C- and S-valves), plug valves, etc., are employed. Attempting to bypass patented designs individual manufacturers of concrete pumps have developed new valve system designs for piston-type concrete pumps [14.36].

A further major advance in the development of systems for controlling the flow of concrete mix in concrete pumps was the use of C- and S-valves. Their operation consists in the alternate connection of the conveying pipe's swing segment fully (S-valves) or partially (C-valves – the elephant-type system) submerged in the concrete mix hopper while the cylinders are in the pumping phase.

In order to minimize wear, concrete mix pumping cylinders are characterized by large diameters, long length, and low rate of displacement. These parameters, in conjunction with reduced speed of the piston as it approaches the dead center and fast switching of the control valves, reduce pumping fluctuations so that the flow of concrete mix is almost continuous.

Pumps are selected depending on the type of structure to be erected. The extreme examples are high-capacity pumps with a short delivery distance versus low-capacity pumps and a long conveying distance. Depending on the application needs, pumps with concrete mix cylinders with a diameter of 100–280 mm and a forcing pressure of 8–26 MPa are used. Pumping capacities range from 20 to 200 m^3/h.

For some construction projects special pumps are built. In the technical literature one can find information about concrete mix pumped to an elevation of 530 m and over a distance of 4000 m (the construction of the Schaeftlarn tunnel). Such pumping distances are achieved when specially designed pumpable concrete mixes are pumped. The design features of these mixes include: the consistency, the cement content, the additives content, and the shape and grading of the aggregates. Another crucial factor is the ambient temperature. A high ambient temperature accelerates concrete mix setting and limits the pumping distance.

Concrete pumps (Fig. 14.41) are usually manufactured as self-propelled machines on chassis or trailers to be towed by a tractor. Concrete pumps mounted on self-propelled chassis are usually powered by the vehicle's engines while those mounted on trailers are driven by a separate engine.

Stationary pumps are fitted with skids or driving axles, which are dismantled on the construction site. They are driven by diesel engines or electric motors.

The choice of a concrete pump (self-propelled, mounted on a trailer or stationary) is determined by economic factors and the character of the construction project. One should take into account that the ratio of the concrete mix placing time to the formwork and to the reinforcement time is relatively low, roughly 1:5.5.

Self-propelled concrete pumps with a distributing boom (Fig. 14.42) ensure very efficient concrete mix transport and distribution.

The distributing boom consists of two, three, four or five segments with a delivery pipe with a rubber hose attached to it. The reach of pumps with a distributing boom is 17–65 m in the horizontal plane. An exemplary nomogram of a 19 m long pump boom's horizontal and vertical reach is shown in Fig. 14.43.

Booms require appropriate chassis and supports. The angle of rotation of the boom around the vertical axis is limited to 270° because the hydraulic conduits feeding the boom folding cylinders are located next to the concrete mix delivery pipe's articulated joint. In order to adapt them better to the characteristics of construction sites, the distributing masts are built as foldable from top or bottom. The folding and slewing of the mast is effected by push-button control. In the case of five-segment masts, folding is effected by a control system following a program.

The approximate commercial specifications of mass-produced self-propelled concrete pumps with a distributing boom are as follows:

Reach in horizontal plane:	12–58 m
Reach in vertical plane:	16–62 m

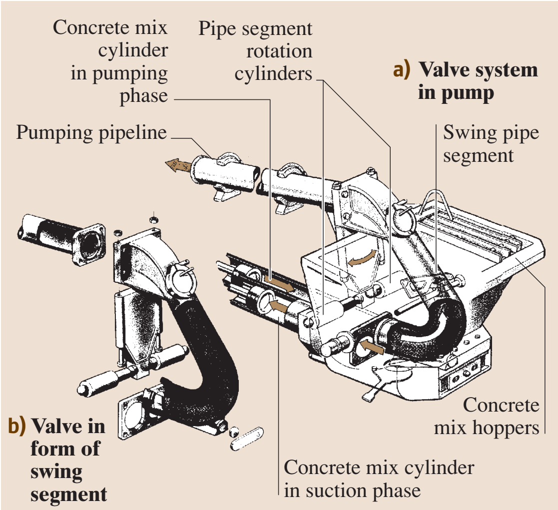

Fig. 14.41a,b Principle of operation of a concrete pump with a valve system in the form of the conveying pipe's swing segment connecting conveying pipe with cylinders during the pumping phase (C-valves – elephant-type system). **(a)** valve system in pump; **(b)** valve in the form of a swing segment

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Slewing angle:	360°
Conveying pipe diameter:	100–125 m
Length of rubber hose for	
Distributing concrete mix:	3.5–5 m
Charging hopper capacity:	350–500 dm^3
Rated pumping capacity:	36–150 m^3/h
Concrete pumping pressure:	45–130 bar
Concrete mix pumping	
Cylinder diameter:	160–230 mm
Piston stroke:	1000–2100 mm
Number of boom segments:	2–5

Self-propelled concrete pumps are also made in versions adapted for attaching a pipeline made from steel pipes for conveying concrete mix over considerable distances.

Besides piston-type concrete pumps also rotary-type pumps, based on the principle of the peristaltic pump, are manufactured (Fig. 14.44).

In the rotary-type concrete pump concrete mix is pumped as a result of squeezing it out of a reinforced rubber hose by two rollers attached to the rotor. The hose recovers its circular cross-section owing to elastic restoration or negative pressure inside the casing (vacuum restore). The pumping pressure in rotary-type pumps amounts to about 3 MPa, allowing concrete mix to be delivered over a distance of about 200 m in the horizontal plane and to an elevation of about 80 m.

The design of the rotary-type concrete pump is simple but the conveying hose needs to be replaced quite often.

Concrete pumps' conveying pipelines are made from 0.5, 2, and 3 m long steel pipes usually 125 mm in diameter, but pipes 100, 150, and 180 mm in diameter are also used.

The pipeline attachments include pipe fittings with 90°, 120°, 135°, 150°, and 165° angles of flare. Individual pipes and pipe fittings are connected by clamping rings and rubber gaskets. The pipeline is tipped with a flexible conduit which facilitates the distribution of concrete mix in a work area.

After work, concrete mix residues are removed by a porous rubber ball forced through by a water jet or compressed air.

Besides the above self-propelled, trailer mounted, and stationary concrete pumps, there are also pumps mounted on tower cranes. These are used on construction sites with a large amount of reinforcement or difficult access for concrete mix placement by other methods, when large-diameter cylindrical tanks are to be built, and so on.

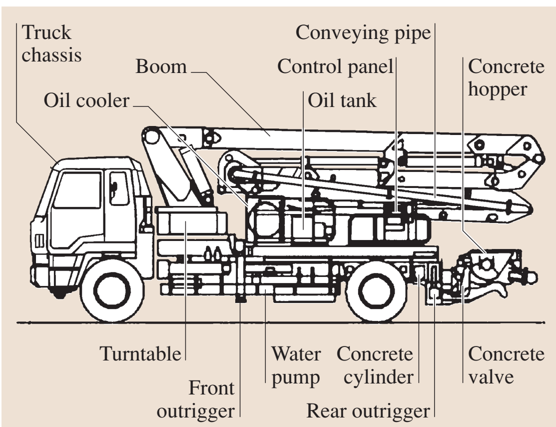

Fig. 14.42 Truck-mounted pump with distributing boom

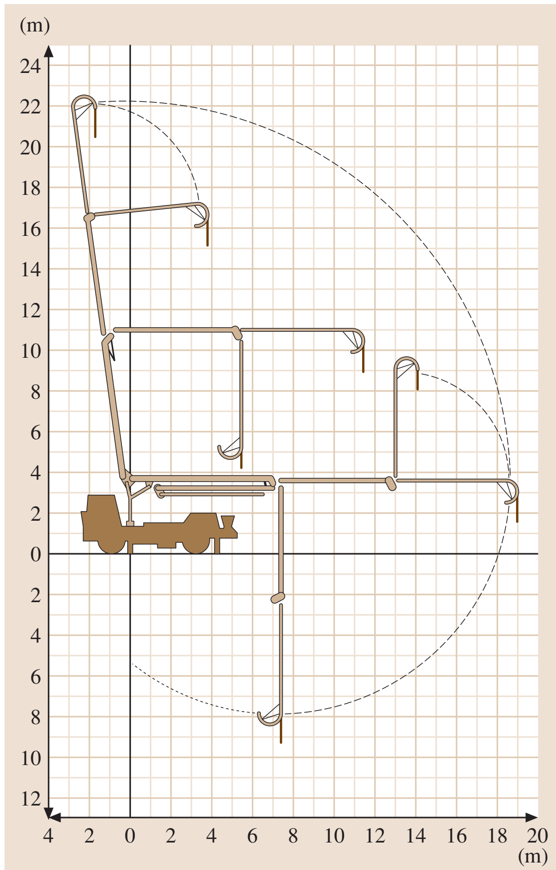

Fig. 14.43 Horizontal and vertical reach of pump with 19 m-long boom

14.3.5 Concrete Spraying Machines

Concrete spraying machines are used for spraying concretes and mortars onto structures. They are mainly used to coat the outer surface of the reinforcement in reinforced concrete structures, steel structures, tensioning cables, slope reinforcements, etc., to protect them against corrosion. Concrete mix can be sprayed onto concrete, rock, and steel bases, brick walls, and wooden formwork. Various kinds of cement concrete, including polymeric concretes and epoxy concretes, can be used for spraying. Sprayed concrete is characterized by good adhesion to the base and chemical resistance.

Besides being used for spraying concrete, concrete mixture sprayers can also be used for sand blasting and conveying concrete mix. In the literature on the subject one can find a third use for concrete sprayers, i. e., semi-wet spraying, which is particularly recommended when concrete mix is to be transported over long distances. Two main modes of operation of concrete sprayers are distinguished [14.37]:

- Dry spraying
- Wet spraying

The operation of a dry mixture sprayer consists of feeding dry components (cement and aggregate) into a charging hopper and pneumatically conveying them to a spraying nozzle, where water is added under a pressure of 0.4–0.6 MPa.

The advantage of the dry method is the possibility of spraying a layer of high-strength concrete owing to the low W/C ratio. A dry mixture sprayer designed for small-sized spraying works is shown in Fig. 14.45.

The machine's main assembly is a rotor mixing the material contained in the space where atmospheric pressure prevails with compressed air at an overpressure of 0.5–0.6 MPa. The principle of operation of the rotor is

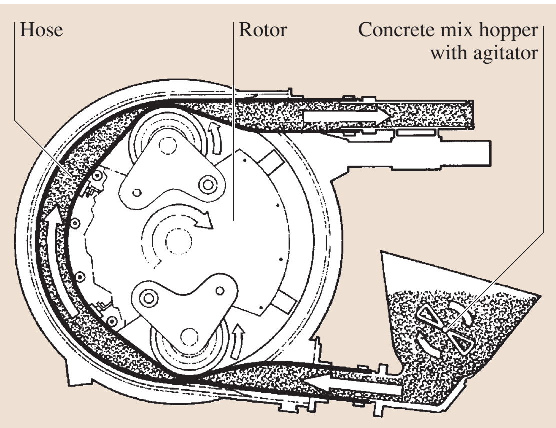

Fig. 14.44 Principle of operation of rotary type concrete pump

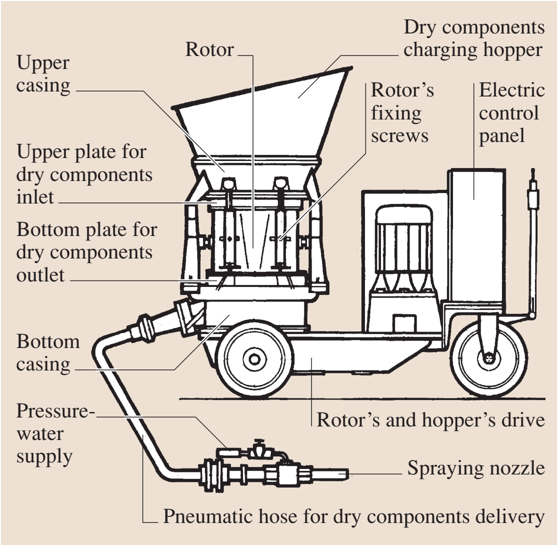

Fig. 14.45 Dry mixture sprayer for small-sized spraying works

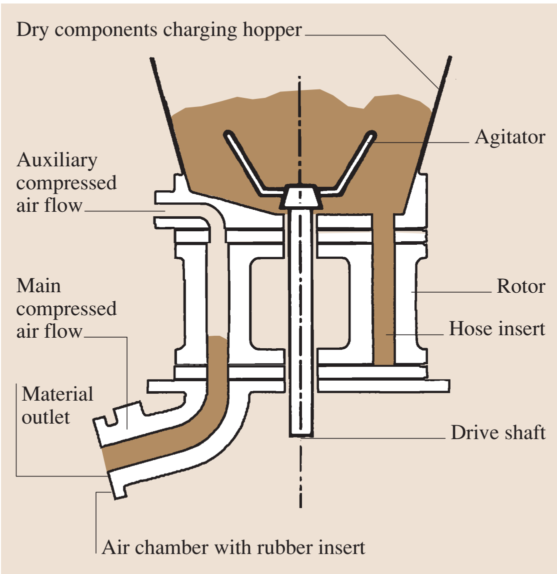

Fig. 14.46 Principle of rotor operation (example of rotor for dry spraying)

illustrated in Fig. 14.46. The aggregate and cement fed into the charging hopper under gravity fall into ports in the rotor and are forced by compressed air into the hose.

Dry sprayers' spraying capacity ranges from 0.2 to 11 m^3/h. Hoses 32, 38, 50, 60, and 65 mm in diameter are most commonly used.

It should be noted that concrete sprayers can also be used to transfer dry concrete mix components over considerable distances – up to 300 m in the horizontal plane and 40 m in the vertical plane – and to sandblast structures.

In wet sprayers ready-made (prepared in separate devices) concrete mix or mortar is conveyed to a spraying tip. In the group of dry sprayers two types of machines can be identified:

- Sprayers equipped with a rotor, in which concrete mix is delivered by compressed air (Fig. 14.47)
- Sprayers in which concrete mix is fed into a spraying tip by means of a concrete pump (Fig. 14.48)

In concrete-pump-type sprayers the concrete mix is conveyed by means of a pump and in the final stage also by compressed air, and is sprayed by a nozzle. Apart from nozzles with compressed air supply, impeller-type spraying units may be used as well.

In smaller devices the spraying nozzle is usually manually guided, whereas in large machines, mainly used in tunnel construction and mining operations, distributing booms wire-guided from portable control consoles are employed. Distributing booms can be mounted as self-contained machines mounted on wheeled or crawler carriers or form an integrated unit with a sprayer as shown in Fig. 14.48. A recent invention, besides nozzles spraying concrete mix by means of compressed air, is impeller-type spraying tips, where concrete mix is sprayed by a rotating impeller, using the centrifugal force directed by the latter assembly. According to the manufacturers, the impeller-type tip causes less dust and the concrete mix losses due to its bouncing off the wall are smaller.

Besides dry or wet mixture sprayers, there are also rotor-type sprayers in which dry and wet mixture spraying processes can be performed alternately after quick reconfiguration.

14.3.6 Internal Vibrators for Concrete

Internal vibrators for concrete are immersed in the concrete mix to transmit vibrations directly to it and thereby cause its compaction. As a result of this vibration the viscosity of the concrete mix decreases and its particles shift quickly relative to one another. The particular grains slide against one another and, due to settling under gravity, expel some of the air and water contained in the concrete mix, resulting in compaction and greater strength of the concrete after curing. When erecting concrete structures, in order to compact concrete mix effectively by means of immersion vibrators appropriate (in terms of frequency and amplitude) vibrators must be used.

The radius of action of an immersion vibrator depends on the exciting force and the frequency and ranges from 20 to 100 cm. Depending on the drive system, flexible drive immersion vibrators, built-in motor type electric immersion vibrators, pneumatic immersion vibrators, and hydraulic immersion vibrators are distinguished [14.38].

Flexible drive immersion vibrators are designed for driving a pendulum (Fig. 14.49) or eccentric vibration generator (Fig. 14.50). Pendulum-type immersion vibrators are driven by an electric motor or a combustion engine and a flexible shaft to which a vibration generator rolling on a raceway is attached.

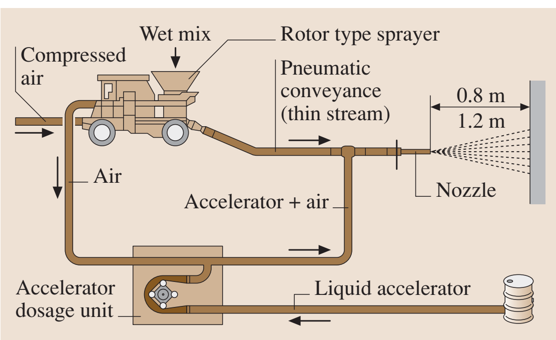

Fig. 14.47 Wet process with use of rotor-type sprayer

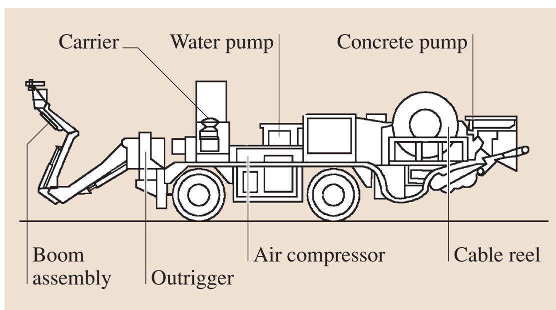

Fig. 14.48 Concrete-pump-type spraying machine (wheeled type)

The diameters of the vibration heads of the vibrators usually range from 25 to 70 mm and the frequencies generated are 300–200 Hz, respectively.

Modern pendulum-type immersion vibrators with a flexible shaft are driven by single-phase commutator motors; under load they can generate frequencies as high as 200 Hz (Fig. 14.50).

The diameters of vibration heads driven by commutator motors are usually 25–65 mm.

Built-in motor type electric immersion vibrators (Fig. 14.51) usually operate in conjunction with a voltage and frequency converter supplying a voltage of 42 V at 200 Hz. They can also be supplied from generating sets with an appropriate rated frequency. Because of the considerable permissible length of the power lead from the generator to the vibration head (about 15 m) these vibrators are suitable for compacting high elements. The vibrator's vibration heads are usually 35–85 mm in diameter and the vibration frequency is 200 Hz.

Pneumatic immersion vibrators are made with vibration heads that are 25–140 mm in diameter. They are characterized by simple design and high durability. These vibrators are used in places where, for safety reasons, it is inadvisable to use electric immersion vibrators or combustion engine immersion vibrators and in places with access to compressed air supply. Depending on their design, their frequency ranges from 160 to 300 Hz.

Hydraulic immersion vibrators are made with an eccentric vibration generator coupled with a hydraulic engine. They are used for compacting concrete mix when building large structures such as dams, bridges, and large foundations. The vibrators are supplied from special hydraulic feeders or from the hydraulic systems of earthmoving machines.

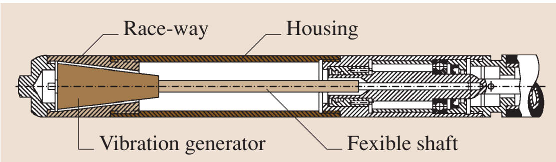

Fig. 14.49 Pendulum-type immersion vibrator

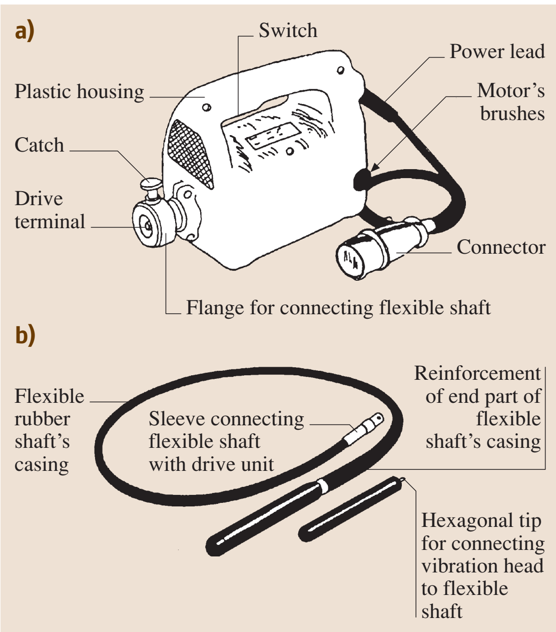

Fig. 14.50a,b Eccentric-type immersion vibrator driven by single-phase commutator motor and flexible shaft: **(a)** drive unit; **(b)** flexible shaft and vibration head

14.3.7 Vibrating Beams

Vibrating beams are used for leveling, compacting, and preliminary smoothing of the top surface of fresh concrete while building horizontally formed structures such as concrete road surfaces, airfields, storage yards, concrete floors in dwellings, and factory floors.

A vibrating beam consists of a rigid beam with a vibration generator mounted on it and flexible connectors for moving the beam. A vibrating beam with a vibration generator in the form of an attachable electric vibrator supplied with a voltage of 42 V is shown in Fig. 14.52.

In order to maintain the rectilinearity of the leveled surfaces and because of the considerable vertical gravity loading and exciting force loading, vibrating beams must have high vertical bending rigidity and relatively low deadweight so that they can be easily carried from one place to another on the construction site. These

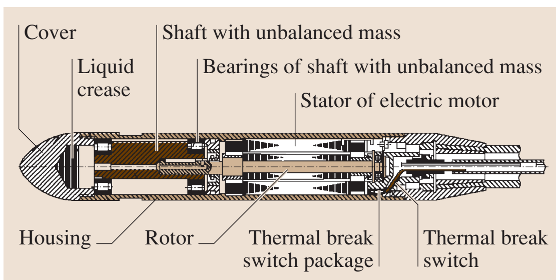

Fig. 14.51 Built-in motor-type electric immersion vibrator

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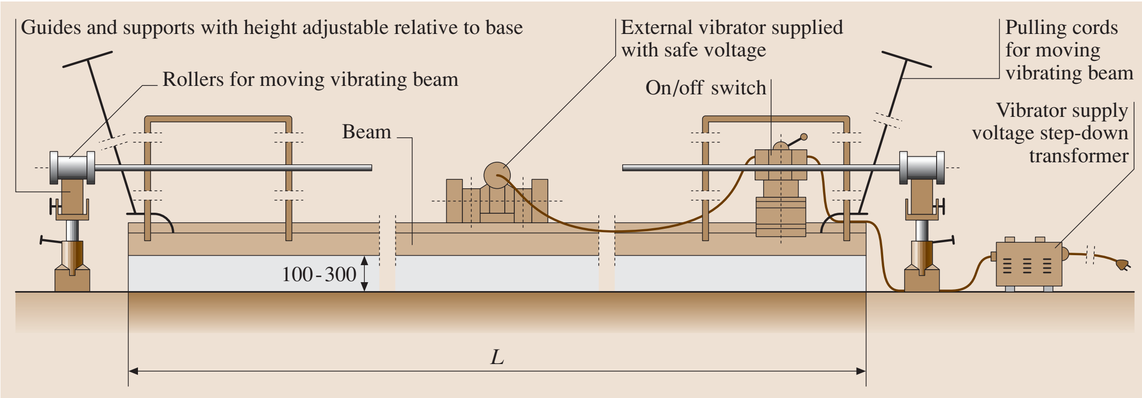


Fig. 14.52 Vibrating beam with vibration generator in the form of an external electric vibrator

requirements are met through the use of beams made from special multihole aluminum sections and by imparting negative deflection to the beams through built-in struts. The beams are used as single elements or double elements connected by lacings.

In order to reduce the harmful effect of vibration on the operators' hands, pulling cords or specially protected handles are used. Attachable vibrators with adjustable exciting force, driven by electric motors, combustion engines or compressed-air engines, are used as the vibration generators. Vibrating beams equipped with attachable electric vibrators are often adapted to a safe voltage supply to eliminate the electric shock hazard.

Vibrating beams of the type shown in Fig. 14.52 are manufactured 2.7–5.7 m long and can compact 10–30 cm thick bases.

The development of vibrating beams is directed towards increasing their length, obtaining uniform compaction of concrete mix along the whole length of the vibrating beam, and improving operational safety and transportability on the construction site. To a large extent the above requirements are met by the multipoint pneumatic vibrating beam shown in Fig. 14.53. The vibrating beam is 6.1 m long and consists of two end segments and one middle segment, joined together by bolts. The individual segments have a lattice structure triangular in cross section. Two stringers, one in the form of an angle and the other a T-bar, form the vibrating beam's base. The upper stringer is made from a pipe, which also serves as the compressed air conduit that supplies the vibrators. The vibrating beam is equipped with 16 pneumatic vibrators spaced at different intervals on both the lower stringers. The vibrators generate vertical vibrations that are transmitted to the concrete mix. The intensity of vibration is linked to the exciting force, the amplitude, and the frequency, and can be adjusted by controlling the supply air pressure. The upper stringer is joined together by turnbuckles which are also used to set the vibrating beam's deflection. The end segments are equipped with manually operated hoisting winches. The above vibrating beams are made up to 18 m long.

Vibrating beams can be equipped with different number of vibrators, depending on the length of the vibrating beam, the thickness of the compacted layer, and the desired surface smoothness. In practice, however, up to two vibrators driven by an electric motor or a combustion engine are used. In the case of reciprocating-motion pneumatic vibrators, this number is about 2–3 vibrators per running meter.

In recent years 1–3 m long smoothing vibrating beams have been introduced. These vibrating beams have low mass and are designed for smoothing elements made of semiliquid concrete mixes. The beam

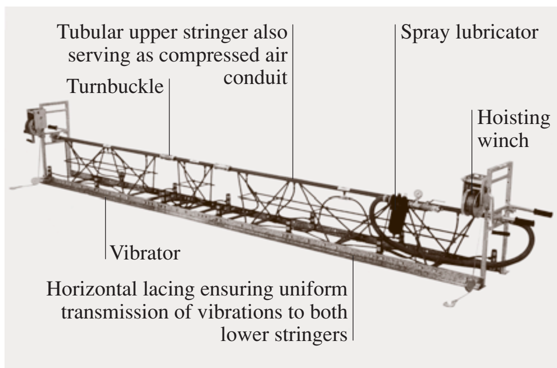


Fig. 14.53 Multipoint pneumatic vibrating beam

is equipped with an attachable electric or combustion engine vibrator and connected in an articulated way to a drawbar guided by one operator. In order to obtain high rigidity the vibrating beam's beam is made from properly formed (by bending) steel or aluminum sheet. Such beams are equipped with one vibrator, driven usually by a combustion engine or an electric motor.

14.3.8 Floating Machines for Concrete

The aim of floating is to obtain a high-quality concrete surface. Floating results in a level surface, a better compacted top surface, greater resistance to abrasion, corrosion, and the destructive effect of moisture, and a reduction in dusting. The floated surfaces can be painted or different kinds of flooring can be glued to them. Floating is performed after the base has gained some mechanical strength.

Rough and finishing floating are distinguished. In the case of older types of floating machines, rough floating was effected using a slowly rotating solid disk, while finishing floating was effected using blades set at an appropriate angle to the base. Now this practice has changed and the entire process is carried out using blades and changing the angle of their inclination, though solid disks are also used.

Single-disk floating machines (Fig. 14.54) are used for smaller concrete works. The working tools are blades or solid disks that are 600–1200 mm in diameter. They are driven by combustion engines or electric motors with a power of up to 8 kW. Combustion engine floating machines feature stepless control of the floating tools' rotational speed. Electric floating machines are equipped with two-speed electric motors whereby one can select the appropriate speed of rotation for the rough and finishing floating tools. Modern single-disk floating machines have the following features:

- A long handle, enabling access to floated surfaces with no need to walk on them (during transport of the floating machine the shaft is folded).
- The angle of inclination of the blades can be adjusted from the handle.
- The machine is equipped with a safety cutout switch (the so-called dead-man's grip), which automatically stops it once the operator's grip on the handle is released.
- Electric protection against switching the opposite direction of rotation.
- Road wheels for short-distance transport.
- The blades and the floating disks are made of high-quality materials to ensure long lifetime.

Two-disk floating machines (Fig. 14.55) are used for floating large surfaces.

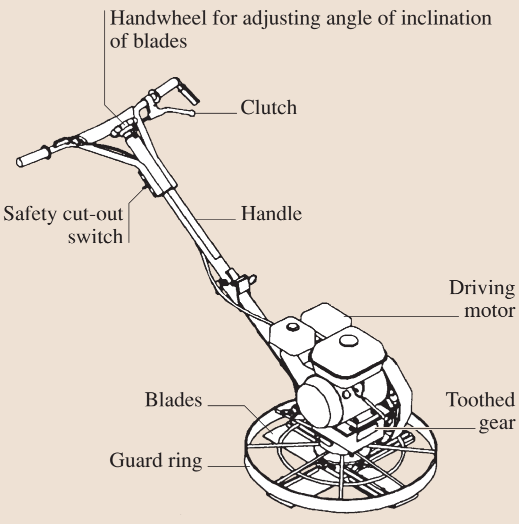


Fig. 14.54 Single-disk floating machine for concrete

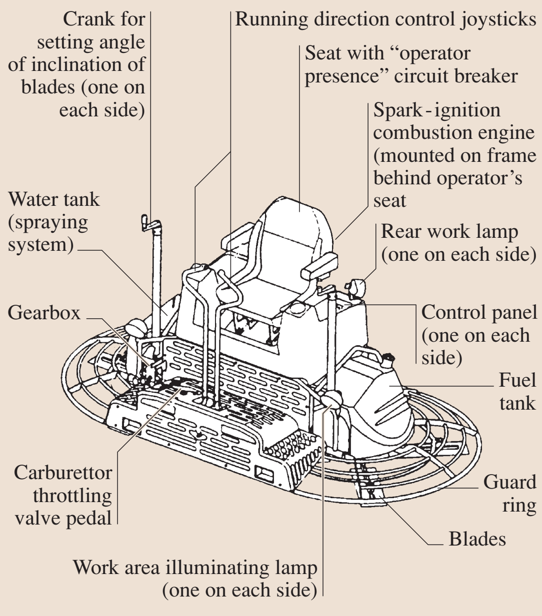


Fig. 14.55 Two-disk floating machine equipped with blades

For these machines the width of the floated strip in one pass ranges from 1700 to 2400 mm. The floating machine's control system consists of push-buttons, two joysticks for controlling the running direction, and two knobs for setting the angles of inclination of the blades.

The operator controls the floating machine while sitting in a centrally situated seat whose symmetry axis coincides with the machine's lateral axis. There are also tandem systems in which the symmetry axis of the operator's seat coincides with the machine's longitudinal axis.

In two-disk floating machines two floating system designs are used. In one of them the floating blades' outline circles may overlap while in the other there is a gap between the outline circles. The former design makes it possible to cover the whole floating width but no solid floating disks can be used. In the latter design floating disks can be used but the pass path needs to be corrected.

Depending on the floating width, machines of this type usually weigh 300–450 kg and the engine's maximum power rating is 24 kW. In the latest designs the mechanical systems are replaced by hydraulic systems, which ensure the smooth operation of the machine.

In two-disk floating machines the angle of inclination of the blades is adjusted by flexible-connector-type control systems. The control of the floating machine's running direction is based on the principle of differentiation of the friction forces acting in the particular quadrants of the outline circles, by changing the inclination of the blade ring. This principle applies to both one- and two-disk floating machines. Control is effected by means of the cranks, for each blade ring independently.

In order to ensure operational safety, safety cutout switches, usually in the form of a pedal pressed during operation by the operator's foot, are used in two-disk floating machines. If the operator falls out of the seat, the floating machine is automatically stopped.

14.3.9 Equipment for Vacuum Treatment of Concrete

Vacuum treatment is used to make high-quality concrete bases and floors. Its advantages include:

- Rapid increase in concrete strength in the initial period after placing concrete mix and applying the vacuum process
- A 15% increase in the final strength and the resulting cement savings
- Improved concrete features such as frost resistance, compression strength, imperviousness to water, and reduction in shrinkage deformation and floor dusting
- Reduction in the harmful effect of low temperatures on the curing of fresh concrete
- Quick execution of works

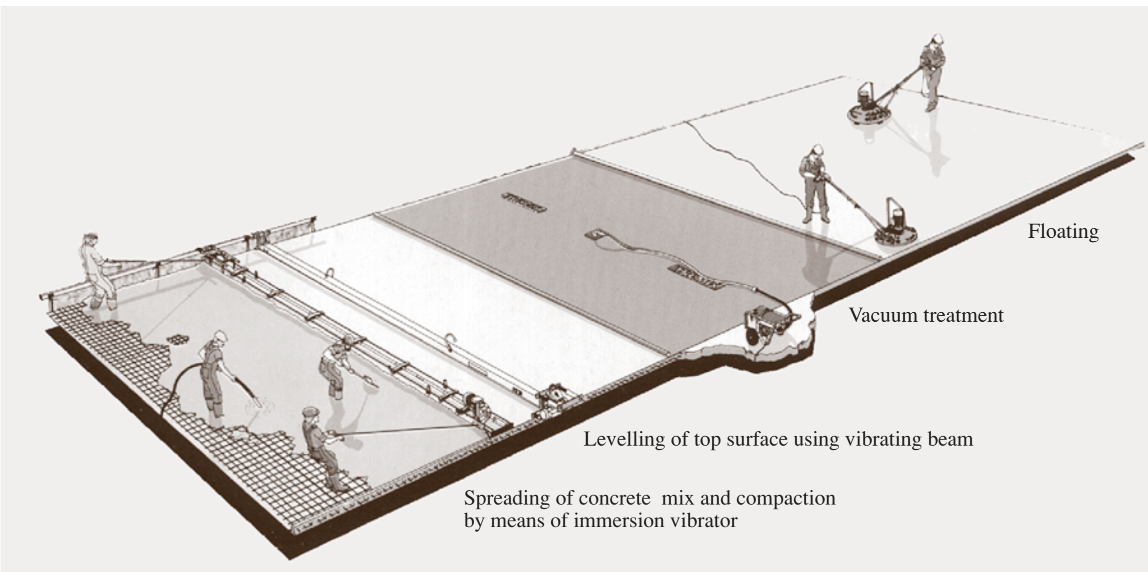


Fig. 14.56 Execution of concrete base with vacuum treatment use

- Ease of spreading of the concrete mix because of its semiliquid consistency

The use of vacuum processing of concrete is especially advantageous at low ambient temperatures (down to −5 °C) since the removal of excessive water and air bubbles to a large extent eliminates destructive processes.

The execution of concrete bases by the vacuum process can be divided into four operations (Fig. 14.56):

- Spreading of concrete and compaction by an immersion vibrator
- Compaction and leveling of the concrete mix's top surface by means of a vibrating beam pulled on guideways
- Covering with a suction mat and vacuum treatment
- Floating of the surfaces by means of rough and finishing floating machines

Roughly, the rate of vacuum treatment is 2 min/cm of base thickness. This means that a 10 cm thick base is treated for about 20 min. Floating is started when a boot impression in the concrete is about 3 mm deep.

The floating equipment includes immersion vibrators, vibrating beams, guideways with supports, expansion-joint inserts, vacuum unit with a suction mat, and floating machines.

The vacuum unit's main assembly (Fig. 14.57) is a vacuum pump with a driving motor. The pump usually has a sealing water-ring. The vacuum unit also includes: a vacuum tank, functioning as a settling tank for the sucked in impurities, connected to an atmospheric tank from which the air and water that has been sucked in is carried off, a wheeled frame, and an electric system.

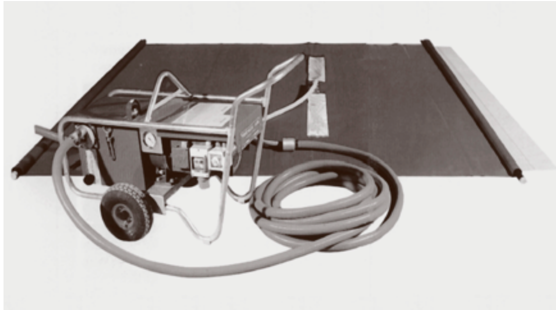


Fig. 14.57 Concrete vacuum treatment unit and suction mat

The development of vacuum units is directed towards reducing the mass and size of the vacuum unit and improving the mat. The currently used vacuum units made by leading manufacturers enable one-time sucking off of a concrete base 60 m^2 in area with a 4 kW driving motor and a machine mass of about 90 kg. The releaent pressure range for vacuum treatment of concrete is 75–95% vacuum (0.75–0.95 kg/cm^2 negative pressure).

Great advances have been made in the design of the suction mat. Older mat designs consisted of three layers, in the form of a filter cloth, a plastic flow mesh, and a tight cover, laid in turn on the vacuumed concrete mix. Current mats are manufactured as one integrated cover performing all three functions, i. e., ensuring the filtration and flow of the sucked off water and air and providing tight covering.

14.4 Site Lifts

14.4.1 Material and Equipment Lifts

Construction material lifts are intended for the vertical transport of building materials during the erection of new buildings and repairs. They may also be employed for the assembly of scaffolds and other construction site protection structures.

A classification of material and equipment lifts according to different criteria is shown in Table 14.1.

The most common type on construction sites are mast lifts with a cable or rack-and-pinion hoisting gear. Depending on the lifting height the lifts can be operated free-standing or anchored. The maximum lifting height of free-standing lifts depends on the stability of the supporting structure. The maximum lifting height of an unanchored lift does not usually exceed 12 m.

Mast Material and Equipment Lifts with Cable Hoisting Gear

The lifting capacity of lifts with a cable hoisting gear usually is below 600 kg.

Examples of lifts with a cable carriage hoisting drive are shown in Figs. 14.58, 14.60 and Table 14.2.

A lift with a capacity of 200 kg (Fig. 14.58) is made up of the following structural units:

Table 14.1 Classification of material lifts

Classification criterion	Lift definition
Platform drive design	Material and equipment lifts with cable hoisting gear Material and equipment lifts with rack-and-pinion hoisting gear
Platform track supporting structure	Material and equipment mast lifts Material and equipment shaft lifts
Base stability securement	Free-standing material and equipment lifts Anchored material and equipment lifts

- A base
- A multisectional mast
- A head with cable pulleys
- A drive unit-cable winch
- A carriage

The carriage moves along the mast, which is secured to the base. The mast is made from sections and has a segmental structure. It can be extended by adding more sections. The mast may be a free-standing structure or a structure anchored by means of special elements to the building's wall or window openings. The carriage is hoisted by a cable system. The winch's cable is guided to the mast's head, where there are cable pulleys through which the cable winds. The cable's end is secured to the carriage, which is equipped with rollers. The carriage suspended on the cable moves along the mast's guides. Accessories for transferring different materials are fixed to the carriage (Fig. 14.59). The carriage can slew around the mast by an angle of about 90°, which improves operating safety during the unloading of materials.

To facilitate the transport of the lift, its base is equipped with vehicle wheels.

Another 500 kg-capacity lift with a cable working platform raising drive is shown in Fig. 14.60.

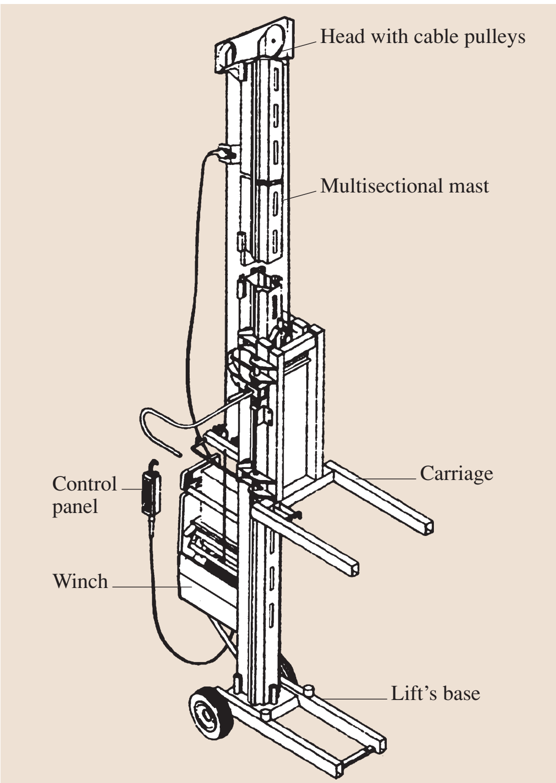


Fig. 14.58 Two-hundred-kilo-capacity lift with cable hosting drive

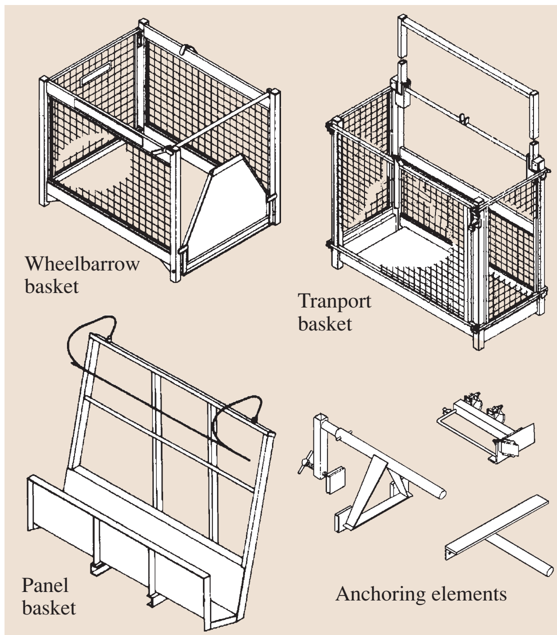


Fig. 14.59 Lift accessories

The lift consists of the following structural units (Fig. 14.60):

- A base
- A cable winch
- A transport basket
- A carriage
- A multisectional mast
- A head with cable pulleys

The basket can slew around the mast by 90°.

The lifts are self-assembled using the provided accessories.

Lifts with a cable hoisting drive are equipped with the following control and safety systems:

- Gripping devices activated when the limit speed is exceeded
- Limit switches making it possible to stop the lift at set stop levels
- A carriage (with the platform installed) upper position limit switch
- A supply-failure emergency carriage lowering system
- Stops in the lift's base

Ladder Lifts

Ladder lifts are cableways for transferring a load simultaneously in the vertical plane and in the horizontal plane. They are employed in the construction and repairs of residential buildings up to 30 m high and are used for roof and indoor work. Ladder lifts enable the transfer of building materials and the removal of waste materials. A typical ladder lift is shown in Fig. 14.61 and Table 14.3.

The ladder lift's main components are: a cable winch, a track, and a carriage.

A cable winch (Fig. 14.61) with a 230 V single-phase, squirrel-cage electric motor is the most popular drive unit used in ladder lifts. The winch includes the following assemblies: an electric motor, a roller gear, a cable drum with a cable, and an electrical system (contactors, relays, overload protections, 230 /24 V transformers).

Winches are mounted on frames attachable to a track segment. They are usually mounted between the truck's two lowest rungs. The drive unit is controlled via a portable control panel. The drive units employed in ladder lifts are very similar to the portable winches described in Sect. 14.6.2.

The main unit of ladder lifts is the track set at an angle for work (Fig. 14.61) It rests against the ground at the bottom and against a structural member (a window frame, the roof's edge) of the building at the top. When a ladder lift is to be used on a sloping roof, a track bend (Fig. 14.61) whose inclination can be adjusted is incorporated and then the track end segments (Fig. 14.61) that are to rest on the roof are attached. The track's section from the base to the building's structural member is supported by an oblique strut. The structural members of the base and the track segments are usually made as ladders whose sides constitute a raceway for the carriage's vehicle wheels. The track is typically made of aluminum alloys, but track members made from tubular steel sections are also commercially available.

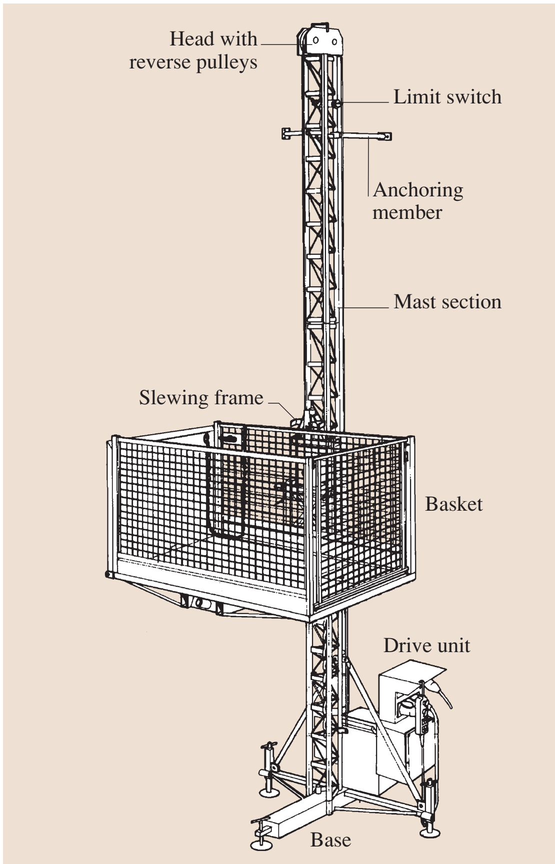


Fig. 14.60 Five-hundred-kilo–capacity lift with cable hoisting drive

Table 14.2 Specifications of cable-driven material and equipment lifts shown in Figs. 14.58 and 14.60

Parameters		
Lifting capacity (kg)	200	500
Lifting speed (m/min)	27	
Maximum lifting height (m)	80	60
Mast section length (m)	2.0	2.0
Mast section weight (kg)	16	30
Distance between anchors (m)	4	4
Gripping device	Yes	Yes
Platform's dimensions		
– Height (m)	max. 1.95	1.0
– Width (m)	0.5–0.75	1.0
– Length (m)	1.15–1.25	1.5
Electric supply (V/Hz)	Single-phase current 230/50	Three-phase current 400/50
Winch motor power (kW)	1.5	3.5
Total mass of lift (kg)	20 m high lift – about 500	20 m high lift – about 775

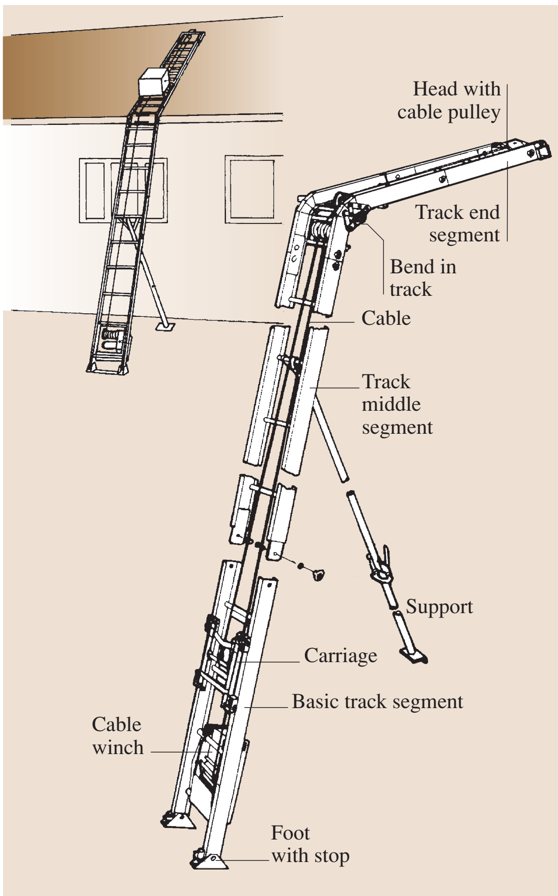


Fig. 14.61 Ladder lift

Within the track structure one can distinguish (Fig. 14.61):

- A base segment
- Middle segments
- A head
- An optional end segment

The base member ends with two hinged feet or a crossbar with wheels, enabling the ladder lift to be rolled without it being necessary to disassemble it.

The middle segments are equipped with locking connectors inserted into adjoining segments and fixed with bolts and nuts.

The track bend has a link mechanism that allows it to be inclined. It also has cable-guiding pulleys.

Another cable-guiding pulley is situated at the end of the track.

The track's accessories include a strut to support its end passing through a window opening.

In some models, the track can be used as the lift's mast for the vertical transport of materials.

The carriage (Fig. 14.61) is the lift's vehicular unit. It is in the form of a frame with vehicle wheels. A cable with a hook, led from the winch to the carriage, runs along the guide and is directed by intermediate cable pulleys and the pulley in the cable track's head. As a rule, the carriage is equipped with an automatic gripping device actuated when the cable breaks.

Accessories for fastening loads are shown in Fig. 14.62. The accessories are mounted on the carriage. They enable efficient and safe materials handling.

Table 14.3 Specifications of model ladder lifts

Parameters	
Lifting capacity (kg)	150–200
Length of track (m)	13–30
Speed of platform (m/min)	18–40
Guide bend angle adjustment (°)	20–45; in some ladder lifts: 0–70
Number of guide sections	9 to 15
Electric supply (V)	230 single-phase alternating current
Motor power (kW)	0.75–1.5
Control	Electrical – through control buttons
Mass of drive unit (kg)	40–55
Mass of guide section (kg)	≈ 10
Total mass of ladder lift (kg)	160–210

Mast Material and Equipment Lifts with Rack-and-Pinion Hoisting Gear

In material and equipment lifts with a rack-and-pinion hoisting gear the platform used for transporting materials climbs a rack running along the mast.

The lift consists of a platform and a mast with a base. The mast structure is segmental. The individual segments have the form of a cuboidal truss structure with a rack attached to one side. Thanks to its segmental structure and the use of appropriate assembly accessories the lift is a self-assembly device. The mast is extended by adding and joining mast sections. The mast is anchored, usually by means of tubular elements, enabling the adjustment of its position relative to the wall of a building. The drive unit mounted on the platform typically consists of an electric motor with a built-in electromagnetically released spring brake, a flexible clutch, a worm gear, and a rack wheel that mates with the mast's rack. In the case of two-mast lifts, two drive units are employed. Examples of material lifts with a platform raising rack-and-pinion hoisting gear are shown in Figs. 14.63, 14.64 and Table 14.4.

The handled materials are loaded and unloaded at stops with transport stages. The mast's base is enclosed by fencing with a control box attached to it. There is an electrically controlled pivoting gate in the fencing. On the entry side all platform stops have sliding barriers which may be equipped with an electric barrier-opening monitoring system for additional protection, so that persons at the stop cannot fall out. Similarly as ca-

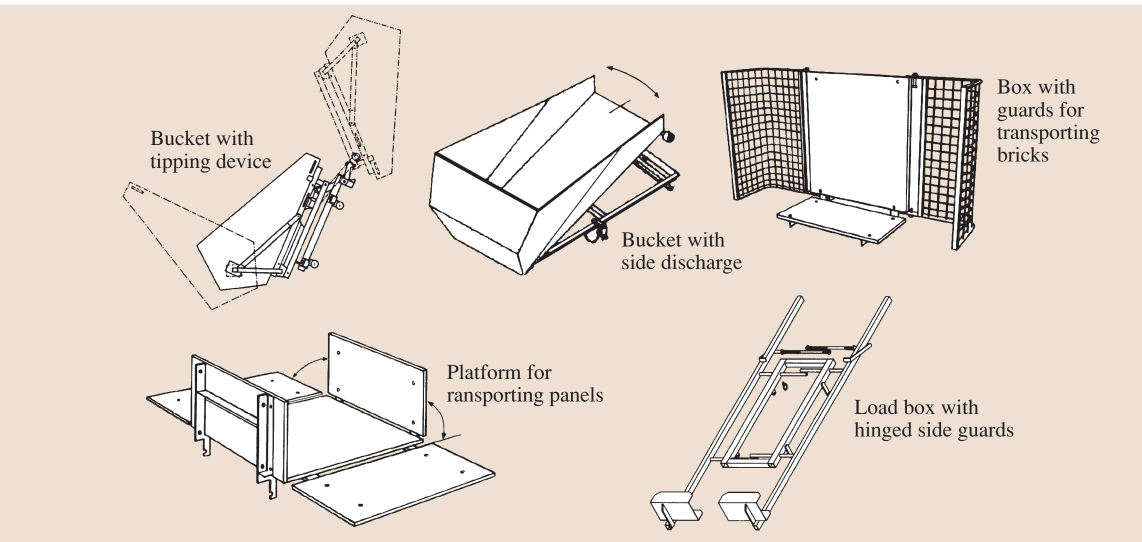


Fig. 14.62 Load fastening accessories

Table 14.4 Specifications of selected material and equipment lifts with rack-and-pinion hoisting gear

Parameters	Single-mast lift	Two-mast lift
Lifting capacity (kg)	600–2000	1500–2000
Maximum lifting height (m)	100	100
Lifting speed (m/min)	About 25	About 25/12
Mast section (m)	1.5	1.5
Height of free-standing mast (m)	9.0	9.0
Distance between anchors (m)	7.5	7.5
Gripping device	Yes	Yes
Platform's dimensions		
– Height (m)	1.1	1.1
– Width (m)	1.5	1.5
– Length (m)	1.5	3.0
Electric voltage (V/Hz)	230–400/50	230–400/50
Hoisting gear motor power (kW)	4.4	2×5.5

ble lifts, lifts with a rack-and-pinion lifting gear may be equipped with a set of wheels to enable them to be easily transported to a new work site. Instead of the platform for handling lump and sacked materials, a special bucket for transporting concrete mix can be installed.

A comparison of lifts with a rack-and-pinion hoisting gear with lifts with a cable hoisting gear shows that the former lifts have several advantageous properties such as: greater lifting height, easier and safer assembly, and simpler operation.

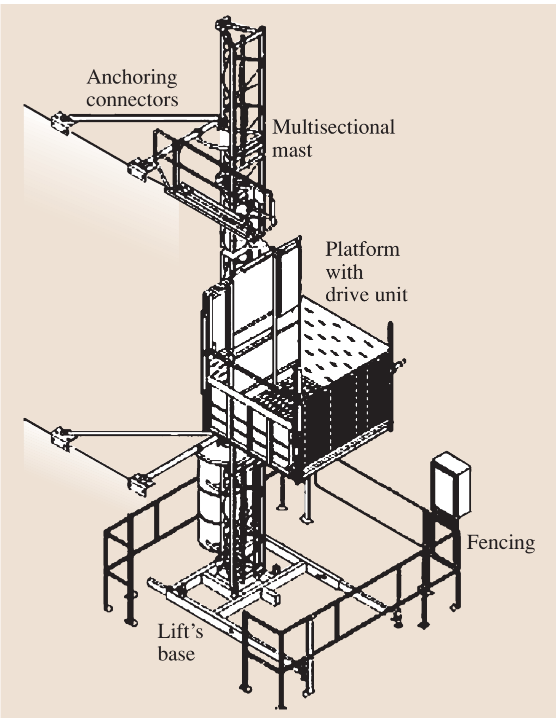


Fig. 14.63 Single-mast material and equipment lift with rack-and-pinion hoisting gear

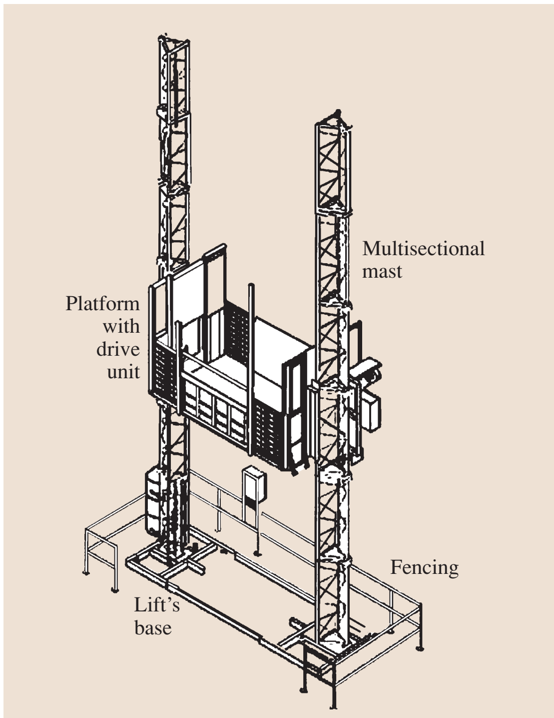


Fig. 14.64 Two-mast material and equipment lift with rack-and-pinion hoisting gear

Table 14.5 Specifications of selected shaft material and equipment lifts

Parameters	
Lifting capacity (kg)	500–1500
Lifting height (m)	15–70
Lifting speed (m/min)	18–33
Platform's dimensions (m)	2 × 1 × 1.5
Electric motor	
– Supply voltage and frequency (V/Hz)	230–400/50
– Motor's power (kW)	7–10
Total mass of 15 m- and 70 m-high lift, respectively (kg)	2300–10 000

Shaft Material and Equipment Lifts

Shaft material and equipment lifts (Fig. 14.65) are used for the vertical transport during the construction of medium- and high-rise building structures.

A shaft lift consists of the following main parts (Fig. 14.65 and Table 14.5):

- A shaft
- An upper beam
- Guides
- A bottom cable pulley
- The platform's upper beam
- A platform
- A winch (typical lifting winches with an electric or diesel drive can be used)

The shaft has a spatial truss structure. The load-bearing platform is made of steel sections. The cable is guided by the bottom and top cable pulleys. The end of the cable is fixed to the upper beam (Fig. 14.65).

There is also a shaft lift design in which the shaft is made of only flat frames anchored to the building's wall. Shaft lifts are equipped with similar safety devices as other material lifts.

Material lifts are equipped with the following safety devices:

- A gripping device which stops the platform as it descends whenever it exceeds the maximum allowable rate of descent.
- Protection against disengagement of the drive wheel from the mast's rack. As standard, sliding guides are used. They keep the load platform on the mast even if the roller guides fail.
- An emergency lowering system used in the case of a prolonged power failure. Some lifts are equipped with emergency lowering systems with speed self-stabilization – the speed stabilizes below the speed at which the gripping device is actuated.
- The upper and lower limit switches, automatically stopping the platform at the mast's highest and lowest levels.
- Switches and locks for stop doors or barriers, preventing their accidental opening when the platform is outside the stop zone or in motion.
- Stops to ensure that the platform will be brought to a stop if the limit switches fail.
- An induction sensor that monitors mast presence during mast assembly.
- A sound system signalling the start of a platform ride.
- Protection against electric shock.
- Overload protection of the electric motors.
- Switches actuated when the working platform skews in two-mast lifts.

The operation of the cable-driven material lifts described above typically consists of the control of the movement of the carriage by pushing buttons on the control panel at the lower station. It is also possible to switch to control from the platform during assembly and maintenance of the lift.

14.4.2 Material and Equipment Lifts with Access to Personnel

Material and equipment lifts with access to personnel are intended for the vertical transport of persons and materials during construction/assembly works and repairs of mainly high-rise buildings in housing and industrial construction. Their design is usually similar to that of material and equipment lifts with a rack-and-pinion hoisting gear.

A person and material lift consists of a cabin with a rack-and-pinion drive, moving on a mast secured at the bottom to the lift's base and anchored to the building's wall, and transport stages (stops) between which transport takes place. The mast has a segmental structure and can be extended by adding mast sections. It is anchored by means of a system of tubes, which makes it possible to adjust the mast's position relative to the building's wall.

The lift can have two cabins, each with its own drive system, whereby the transport of persons and materials can be doubled. The lift's cabins move on a common mast independently of each other. Examples of person

Table 14.6 Specifications of selected person and material and equipment lifts

Parameters	Single-cabin lifts	Two-cabin lifts
Lifting capacity (kg)	1200–2000	2 × 1200–2 × 2000
Maximum lifting height (m)	150–300	150–300
Maximum number of persons	15–25 depending on lifting capacity	15–25 depending on lifting capacity
Lifting speed (m/min)	≈ 40	≈ 40
Mast section (m)	1.5	1.5
Distance between anchors (m)	12.0–15	12.0–15
Lifting height without anchoring (m)	12.0–15	12.0–15
Davit's lifting capacity (kg)	150	150
Gripping device	Yes	Yes
Cabin's dimensions		
– Height (m)	2.1–2.7	2.1–2.7
– Width (m)	1.3–1.5	1.3–1.5
– Length (m)	≈ 3.0	≈ 3.0
Electric specifications		
– Supply voltage and frequency (V/Hz)	230–400/50	230–400/50
– Motor power (kW)	2 × 9.0–2 × 11	2 × 2 × 9.0–2 × 2 × 11

and material lifts with a rack-and-pinion, platform lifting gear are shown in Figs. 14.66, 14.67 and Table 14.6.

The development of high-rise construction created a need for high-lifting-speed vertical transport equipment. For this purpose fast lifts with a lifting speed of up to 1.8 m/s are employed. These are used for the vertical transport of persons and materials and equipment in industrial construction, for building reinforced concrete chimneys, silos, television towers, and similar structures. One- and two-mast high-speed construction lifts are available.

These lifts incorporate electrohydraulic drive systems whose basic unit is a hydrostatic gear. The hydraulic engine's output shaft is connected by a cou-

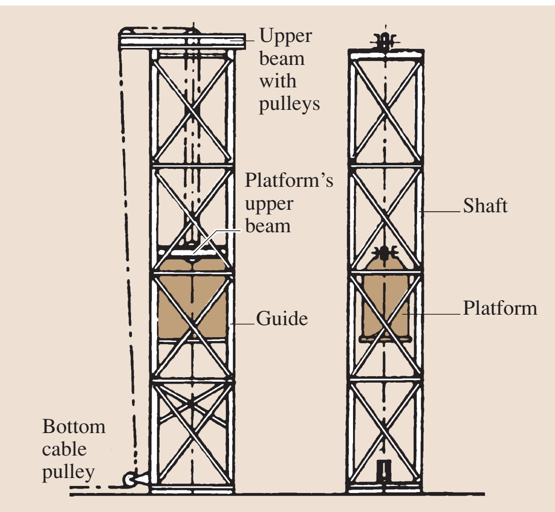


Fig. 14.65 Shaft material and equipment lift with cable hoisting gear

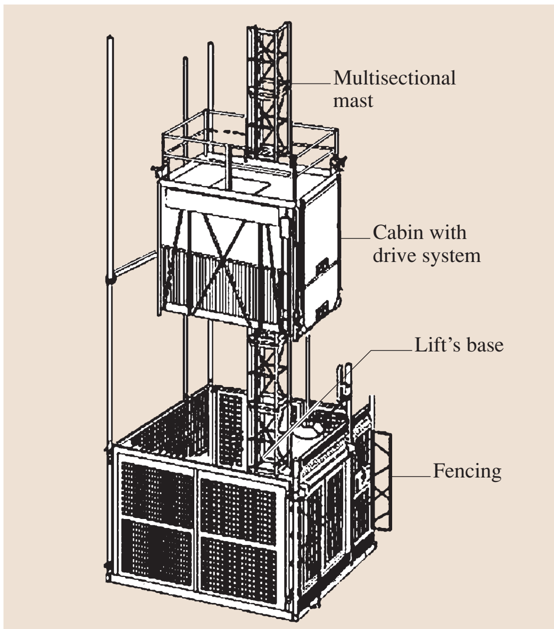


Fig. 14.66 Single-cabin person and material lift with rack-and-pinion hoisting gear

pling to the shaft of a worm gear assembly on the output shafts of which cylindrical gears mating with the mast's rack, and so making the cabin move up or down, are mounted. The weight of the loaded cabin is counterbalanced by a counterweight connected to the cabin by a steel cable passing through pulleys fixed to the top of the mast.

The safety of persons in person and material lifts is ensured by appropriate guards around the traffic way and the stop platform access. Person and material lifts can be controlled from the moving cabin as well as from any stop level. The lift's base (the bottom stop) is fenced in to a height not less than 2.0 m. The access areas are protected by stop doors with a minimum height of 2.0 m, equipped with safety locks.

Entrances to the person and material lifts' cabins are protected by doors. The cabin door is equipped with mechanical bolting devices and safety cutout switches, preventing the door from being opened as the cabin is moving when the cabin's floor is not within about ± 0.25 m from a stop landing or when the door is not closed and the bolting device is not in the closed position.

In addition, person and material lifts are fitted with similar safety devices as those used in rack-and-pinion material and equipment lifts, i. e.:

- Gripping devices actuated at an excessive speed of descent
- Protection against disengagement of the drive toothed wheel from the mast's rack
- An emergency lowering system
- Limit switches
- Working platform skewness switches in two-mast lifts
- Protection against electrical failures in the case of no voltage, voltage decay, or voltage drop
- Electrical devices protecting:
  - Closed stop gate position
  - Stop gate bolting device position
  - Closed cabin or platform gate position
  - Bolted emergency hatch or door position

Modern rack-and-pinion person and material and equipment lifts are characterized by:

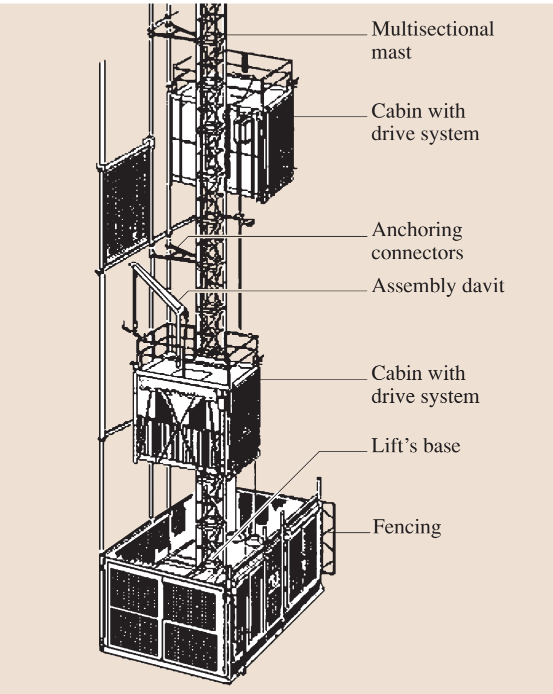


Fig. 14.67 Two-cabin person and material lift with rack-and-pinion hoisting gear

- A great lifting height: up to 300 m
- Easy and quick assembly
- A high lifting capacity: 2000 kg per cabin
- Automatic stopping of the cabin at the terminal stops
- The possibility of programming at which stops the cabin should stop
- Completely safe operation owing to the use of appropriate protective measures
- Easy operation and simple maintenance
- An installation that enables audio communication between the cabin and the bottom stop
- An overload control system

Because of their advantages person and material lifts with a rack-and-pinion hoisting gear have gained a dominant position in the lift market.

14.5 Access Machinery and Equipment

14.5.1 Static Scaffolds

A scaffold is a temporary (usually bar) structure erected to provide safe access during construction, repair, maintenance, and demolition of all kinds building structures.

Scaffolds can be classified according to the different criteria specified in Table 14.7, and the main criteria for classifying scaffolds and the related terminology are described below.

One of the major criteria is the division of scaffolds with regard to their design and assembly method. Particularly important is the division into tube–coupler scaffolds and system scaffolds.

Tube–coupler scaffolds (Fig. 14.68) are constructed from steel tubes and couplers, and the stagings are made from boards or balks. In this type of scaffolds, the dimensions of the structural grid are not rigidly imposed by the dimensions of the components, e.g., by the length of the tubes. Workers assembling a tube–coupler scaffold according to a blueprint ascertain the positions of all the elements which determine the dimensions of the structural grid and the verticality of the uprights. The basic components of the tube–coupler scaffold are shown in Fig. 14.68.

In tube–coupler scaffolds, such elements as standards, transons, and bracings are joined eccentrically by right-angle or swivel couplers, as illustrated in Fig. 14.69.

A characteristic feature of *scaffolds made of prefabricated elements* (system scaffolds) is that their dimensions (or some of their dimensions) are determined by the dimensions of their components. All frame and modular scaffold systems belong to this class. A general view of system scaffold constructions is shown in Fig. 14.70. Modular scaffolds and frame scaffolds are shown on the left and right, respectively.

In the *frame scaffold*, the vertical structure is made up of prefabricated flat frames. The frame consists of two uprights permanently connected by transverse el-

Table 14.7 Classification of scaffolds

No.	Classification criterion	Name of scaffold	
1	Intended use	Working scaffold Protective scaffolds Load-bearing scaffolds	
2	Design and assembly method	Tube–coupler (bricklayer's) scaffolds Ladder scaffolds Scaffold made of prefabricated elements (system scaffold)	 Modular Frame
3	External load-bearing mode	Standing scaffolds Suspended scaffolds Trestle scaffolds Outrigger scaffolds Cantilever scaffolds	
4	Protection of scaffold against overturning	Anchored facade scaffolds Scaffolds secured to base by guy-ropes Free-standing scaffolds	
5	Transferability	Immobile (stationary) scaffolds Mobile (portable) scaffolds	
6	Operating mode	Scaffolds used for short periods, e.g., during working shift Permanent scaffolds used for prolonged periods without dismantling	
7	Material from which scaffold load-bearing elements are made	Wooden scaffolds Aluminum scaffolds Steel scaffolds	
8	Technical–organizational and formal-legal aspects	Scaffolds in typical version Individually designed scaffolds	

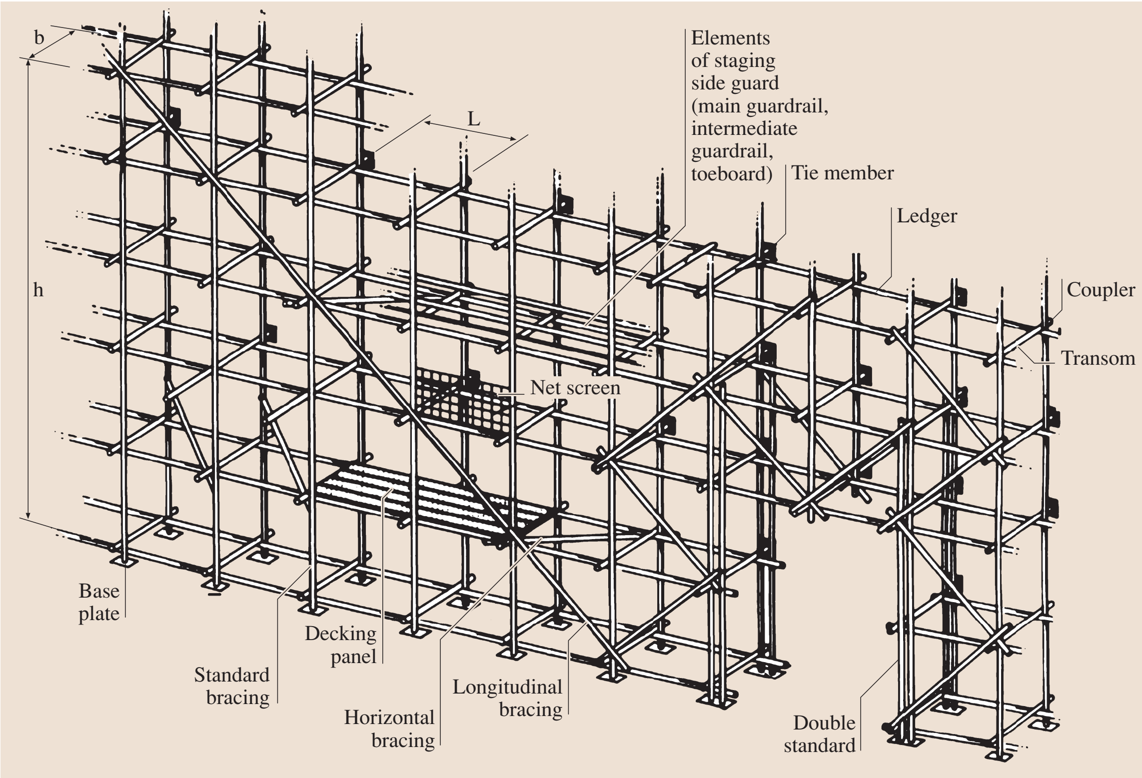


Fig. 14.68 Anchored facade tube–coupler scaffold (*b* scaffold width; *L* scaffold length; *h* scaffold height)

ements at the frame's top and bottom. The top cross member is used for fixing decking panels. The bottom member may prevent the disassembly of the decking panel while the scaffold is in service. In the vertical plane the scaffold is braced by diagonal bracings. In the horizontal plane it is braced by system decking panels.

In a modular scaffold, transoms, ledgers, and bracings are joined with standards at fixed nodal points spaced at regular intervals, usually every 0.5 m.

Modular and frame scaffolds made by one manufacturer are in most cases compatible and can be combined.

In frame system scaffolds, uprights are connected with crossbars by inseparable welded joints.

In *modular system scaffolds*, standards are joined with transoms at fixed nodal points.

Transoms and bracings can be attached to standards by means of coupling elements permanently fixed to the latter. The coupling elements (coupling heads) usually have the form of a disk or a flange and they are regularly spaced, usually every 0.5 m. The bracings and the transoms are tipped with coupling heads. Transoms and bracings are connected with standards, typically by cotter joints. As opposed to tube–coupler structures, in modular scaffolds the axes of the ledgers, the transoms, and the standards connected together intersect at one point. A modular scaffold joint is shown in Fig. 14.71.

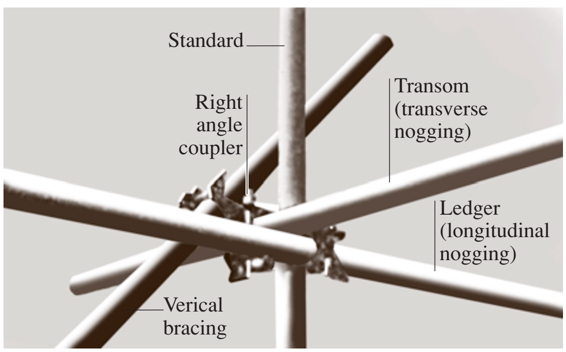


Fig. 14.69 Tube–coupler scaffold joint

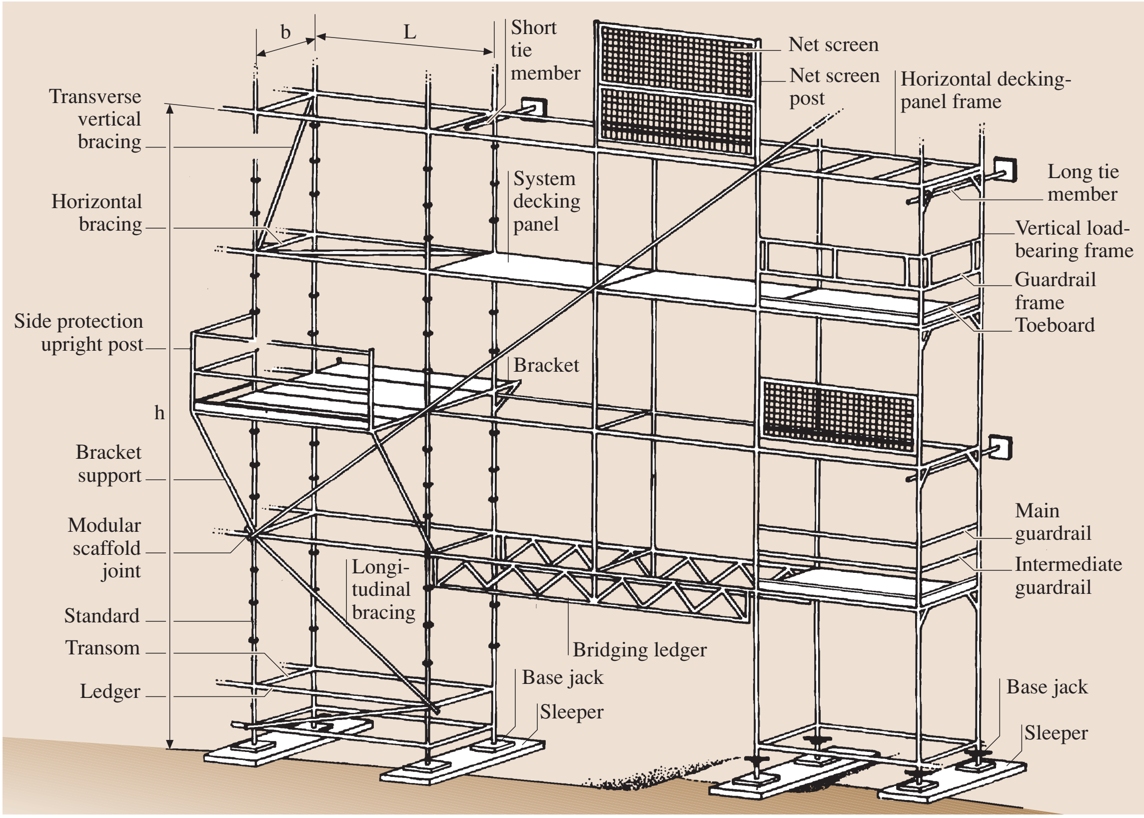


Fig. 14.70 Anchored facade system scaffolds frame scaffold (*right*) and modular scaffold (*left*) (*b* scaffold width; *L* scaffold length; *h* scaffold height)

System scaffolds have several advantages over tube–coupler scaffolds:

- Much easier, quicker, and safer assembly
- Higher load capacity at similar or identical scaffold geometrical or material specifications
- Lower and easier to assess variability of the scaffold structure's random parameters such as geometric imperfections, the load capacities of the individual elements, and the characteristics of the joints
- Possible greater standardization of typical designs

For these reasons tube–coupler scaffolds are being supplanted by system scaffolds.

Another major criterion according to which scaffolds are divided is their intended use. This is connected with the character and magnitude of the loads acting on the assembled structure. Two basic uses can be distinguished:

- Working scaffolds – structures capable to carry worker, material, and equipment loads.
- Load-bearing scaffolds – support structures which, during the construction of a building, can be loaded with the weight of its individual elements or units; one should note that the reliability of scaffolds of this type is a necessary condition for the proper course of a construction process (e.g., concreting). The construction and use of load-bearing scaffolds is subject to separate regulations.

Another major scaffold classification criterion is connected with technical–organizational and formal–legal aspects and with the standardization of scaffold designs and applications.

In legal instruments scaffolds are divided into:

- Scaffolds in a typical version
- Individually designed scaffolds

Table 14.8 Specifications of typical portable single-mast climbing platforms

Parameters				
Platform's length/lifting capacity (m/kg)	4.1/1300 7.1/800 10.1/500	4.2/1300 7.4/1000 10.5/700	4.2/2000 7.4/1700 10.5/1400 12.5/1200	4.2/2700 7.3/2300 10.5/1900 13.7/1500 16.9/1000
Maximum platform elevation without anchoring – Protractible beams protracted on both sides (m) – Protractible beams protracted on one side of mast (m)	 6 6	 20 15	 15 15	 18–20 13–15
Maximum platform elevation with one mast anchoring point located at top (m)	11.5	25	25	25
Maximum platform elevation with anchoring along entire length of mast (m)	100	200	200	200
Spacing between anchors (m)	6	12.5	12.5	12.5
Max. length of platform's protractible part (m)	1.0	0.3	1.4	2.5
Max. loading of struts (kN)	15	50	60	65
Lifting speed (m/min)	6	6	6	6
Transport mass (kg)	1800	3500	4000	4000
Mast section: length/weight (mm/kg)	1508/48	1256/82	1256/82	1256/82
Electric specifications of platform lifting gear	400 V/50 Hz 3 kW, 16 A	400 V/50 Hz 3 kW, 16 A	400 V/50 Hz 3 kW, 16 A	2 × 400 V/50 Hz 3 kW, 16 A

A scaffold in a typical version means an assembly version of the scaffold which covers the most frequent applications of the scaffold structure. It is assumed that the manufacturer has provided a proof of the scaffold's static strength and neither its user nor the company assembling it has to provide such a proof in order to certify the scaffold fit for use on the construction site. Also in the case when the assembly version has been realized in accordance with a generally recognized assembly standard the proof does not have to be provided. The generally recognized assembly standard may be defined in assembly norms or instructions issued by the manufacturer of the given type of scaffold.

Scaffolds in a typical version are anchored, facade, working scaffolds with a height of up to 24 m and access working towers erected to a height of 8 m outdoors and to a height of 12 m indoors.

Typically, a useful load of 2 kN/m^2, sometimes 0.75, 1.5, 3, 4.5, and 6 kN/m^2, is assumed for stagings.

Examples of scaffolds in their typical versions are shown in Fig. 14.72.

Each scaffold that is not in a typical version should be individually designed and its statics tested. The range of the structural analysis depends on the complexity of a given scaffold structure. Examples of atypical scaffolds are shown in Figs. 14.73–14.77.

Competent construction design companies, usually connected with equipment manufacturers, should be entrusted with the design of atypical scaffolds. When selecting scaffolds the user should take into account the following:

- The construction site's location (a wind load zone, power lines, traffic routes, etc.)
- The kind of terrain and the lay of the land on which the scaffold is to be founded

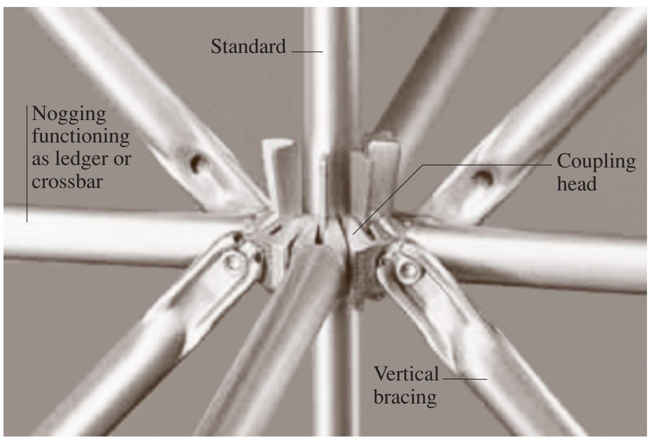


Fig. 14.71 Modular scaffold joint

- The bearing capacity of the base on which the scaffold is to be founded
- The building's height and the shape of the elevation
- The kind and type of scaffold
- The intended use of the scaffold
- The magnitude of the loads originating from people and equipment
- Easy anchoring of the scaffold
- The number and layout of traffic routes
- The transport of materials onto the scaffold
- Canopies

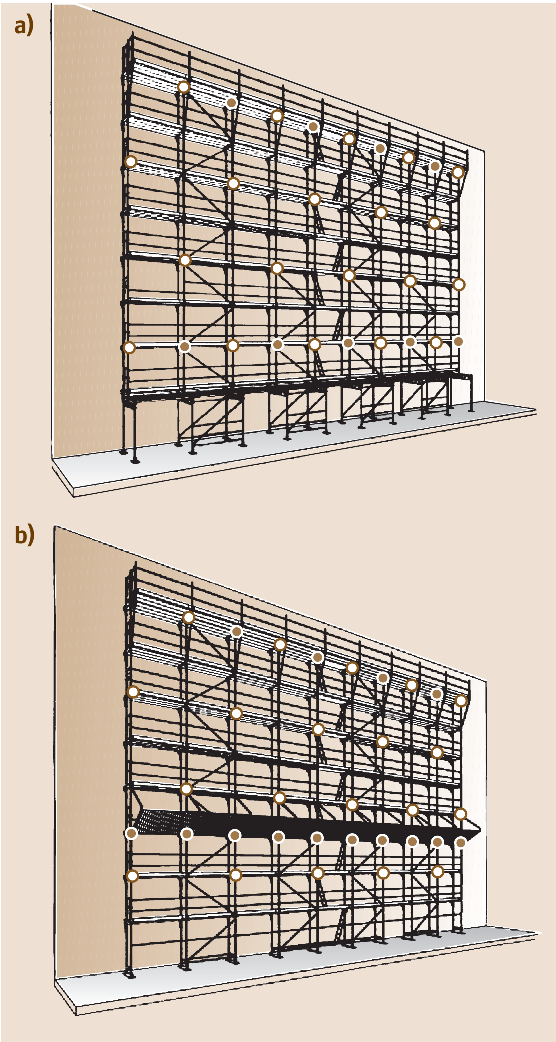


Fig. 14.72a,b Example of anchored, facade, frame scaffold in typical version: **(a)** version with first story constructed from intermediate frames; **(b)** version with canopy

- The assembly of a typical or an atypical scaffold
- Renting or purchasing costs

14.5.2 Elevating Work Platforms

General

Elevating work platforms form a wide class of cranes for elevating persons and equipment for repair, maintenance, and assembly purposes. Depending on their design and application, elevating work platforms can be divided into the following groups:

- Portable mast-climbing platforms
- Mobile (mounted on special chassis) elevating work platforms
- Hanging scaffolds

Portable Mast-Climbing Platforms

Portable mast-climbing platforms are used for masonry plastering, assembly, insulation, and facade works in housing and industrial construction. Portable mast-climbing platforms (Figs. 14.78 and 14.79 and Tables 14.9 and 14.10) are made up of the following units:

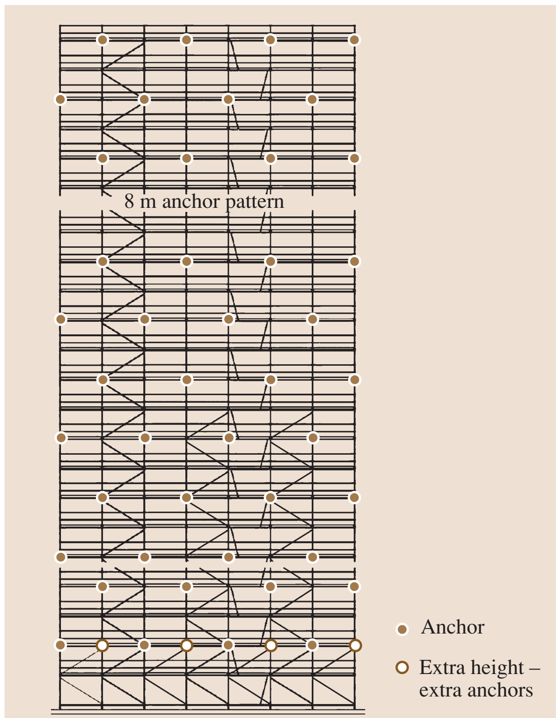


Fig. 14.73 Anchored, facade, frame scaffold in atypical version. The atypicality consists of the considerable height of the scaffold

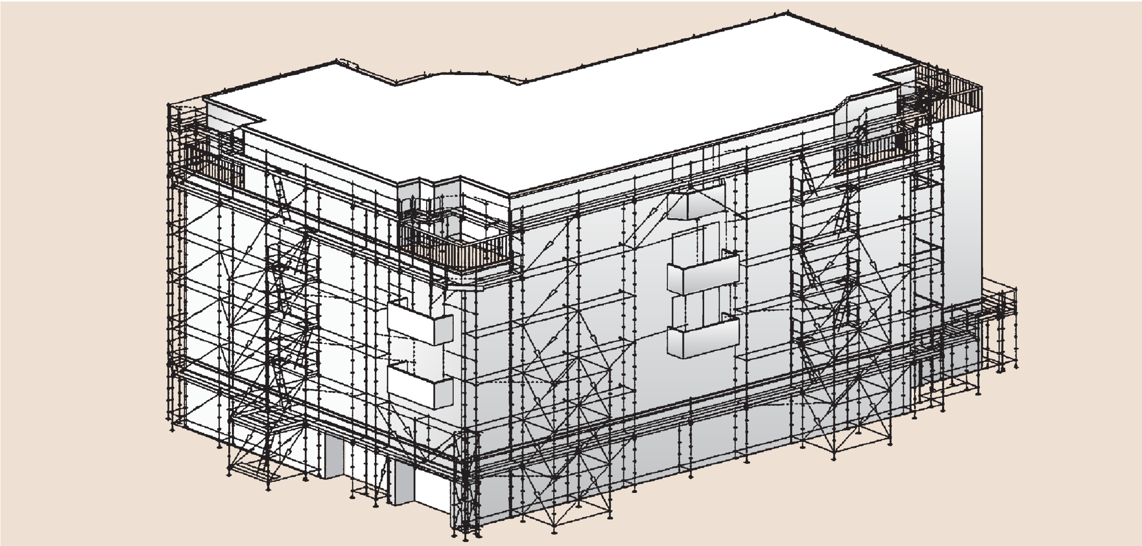


Fig. 14.74 Facade, frame scaffold in atypical version. The atypicality consists of the lack of anchoring

- A base
- A mast or multisectional masts
- A work platform lifting unit
- A work platform

The work platform moves on a mast fixed to a base and anchored to a wall of a building structure. The mast is

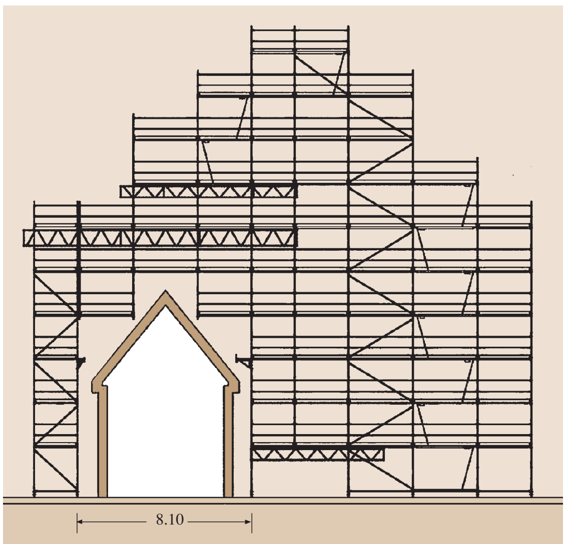


Fig. 14.75 Anchored, facade, frame scaffold in atypical version. The atypicality consists of the part of the scaffold suspending on girders

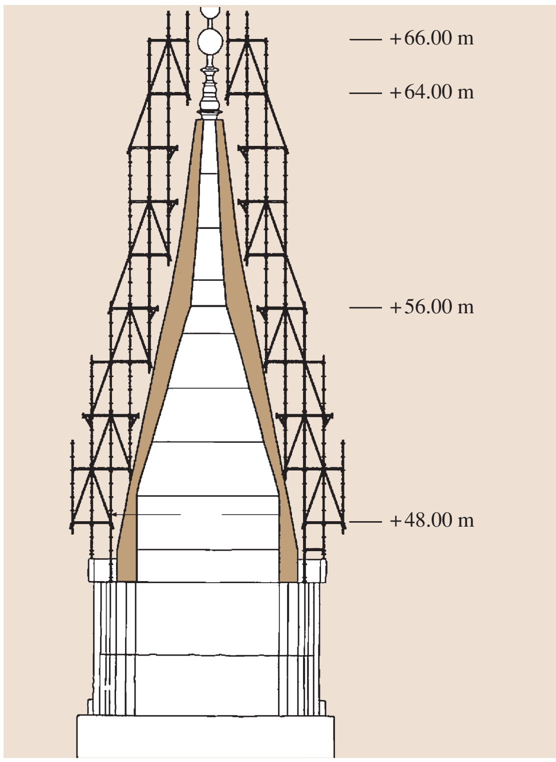


Fig. 14.76 Facade, frame scaffold in atypical version. The atypicality consists of the shape of scaffold support scheme, which differs greatly from the typical version

Table 14.9 Specifications of typical portable two-mast climbing platforms

Parameters				
Platform's length/lifting capacity (m/kg)	4.1/1300 7.1/800 10.1/500	4.2/1300 7.4/1000 10.5/700	4.2/2000 7.4/1700 10.5/1400 12.5/1200	4.2/2700 7.3/2300 10.5/1900 13.7/1500 16.9/1000
Maximum platform elevation without anchoring				
– Protractible beams protracted on both sides (m)	6	15	10	20
– Protractible beams protracted on one side of mast (m)	6	15	15	12.5–17.5
Maximum platform elevation with one mast anchoring point located at top (m)	11.5	25	25	25
Maximum platform elevation with anchoring along entire length of mast (m)	100	200	200	200
Spacing between anchors (m)	6	12.5	12.5	12.5
Max. length of platform's protractible part (m)	1.0	0.3	1.4	2.5
Max. loading of struts (kN)	15	50	60	65
Lifting speed (m/min)	6	6	6	6
Transport mass (kg)	3700	2 × 3500	2 × 4000	2 × 4000
Mast section: length/weight (mm/kg)	1508/48	1256/82	1256/82	1256/82
Electric specifications of platform lifting gear	400 V/50 Hz 3 kW, 16 A	400 V/50 Hz 3 kW, 16 A	400 V/50 Hz 3 kW, 16 A	2 × 400 V/50 Hz 3 kW, 16 A

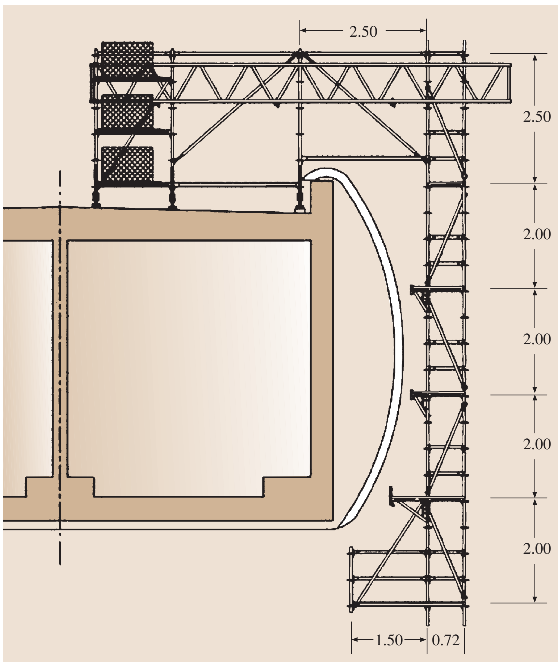


Fig. 14.77 Atypical suspended scaffold. The atypicality consists of the suspending main part of scaffold

made up of sections added up to the required height. In the case of a free-standing mast, the work platform can be usually lifted to a height of 20 m. The mast's base can have the form of a carriage or be stationary. If a carriage is used as the base, the free-standing mast-climbing platform can be moved without it being it necessary to disassemble the mast completely. The carriage can be towed by a tractor or be self-propelled and so able to move along the wall of the building structure. A small-sized stationary base is used when the space for the mast-climbing platform is restricted and no carriage can be employed, e.g., in a street with a narrow pavement. The work platform is elevated by a rack-and-pinion gear. Thanks to its sectional design the mast-climbing platform can be configured to fit the building structure's shape.

In addition, protractible struts, with length adjustable from 0 to 2500 mm, can be attached to the mast-climbing platform's sections. Planks or wooden boards are placed on the beams, thereby creating additional working surface. The combination of the mast-climbing platform's sectional structure and the system of protractible struts makes it possible to obtain work access on walls of any shape (straight, curved, and with slants and bevels) and architectonic form (balcony,

loggia, niche, bay). The whole mast-climbing platform is fenced in with railings to protect persons working on it from falling out. It is also possible to combine two single-mast climbing platforms to form one platform (up to 40 m long) climbing two masts (Fig. 14.79 and Table 14.10). In many cases, mast-climbing platforms may replace stationary construction-assembly scaffolds.

Similarly to material hoists and person and material hoists with a rack-and-pinion drive, mast-climbing platforms are equipped with the following safety devices:

- An emergency lowering system
- A braking device
- A safety device preventing the driving gear wheel from disengaging from the mast's gear rack
- Electric-shock protection
- Overload protection for the electric motors
- Work-platform-slanting cutouts (in two-mast climbing platforms)
- Work platform terminal position cutouts
- Sensors signalling a platform loading which may result in overturning of the mast-climbing platform or its damage

Mobile Elevating Work Platforms

Mobile elevating work platforms have a similar range of applications (elevating persons and equipment) as the portable mast-climbing platforms described above, except that their use in one work place is short.

Mobile elevating work platforms form a class of devices varied in their design. The basic types of mobile elevating work platforms are listed in Table 14.10.

Mobile elevating platforms are usually equipped with protractible struts. Truck-mounted platforms are the most popular mobile elevating work platforms used in construction.

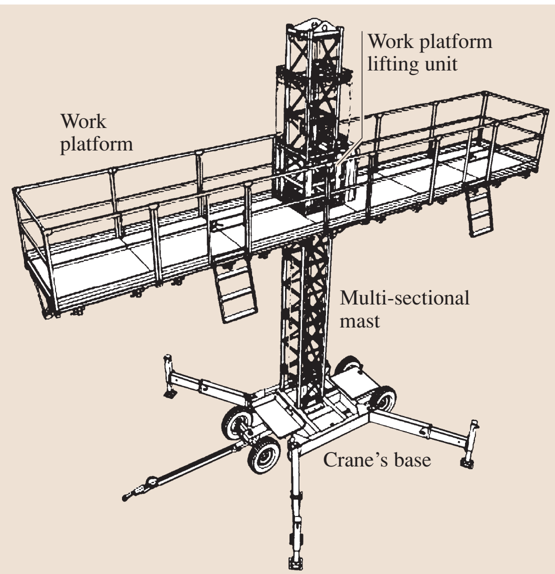


Fig. 14.78 Portable single-mast climbing platform with rack-and-pinion lifting gear

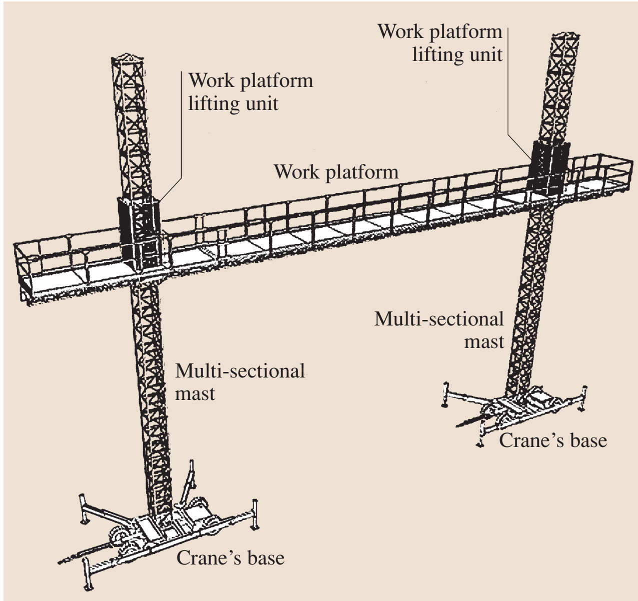


Fig. 14.79 Portable two-mast climbing platform with rack-and-pinion lifting gear

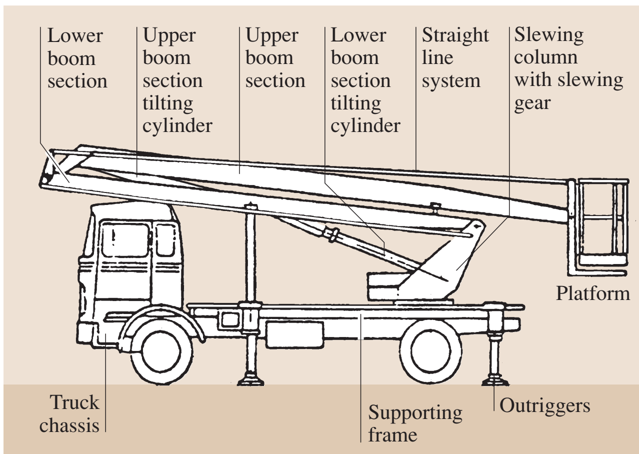
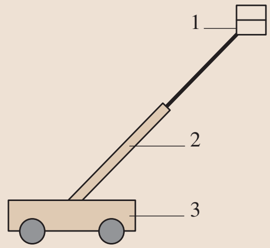
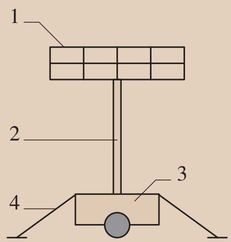
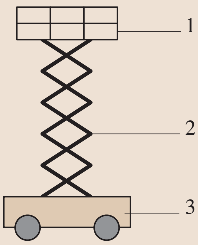
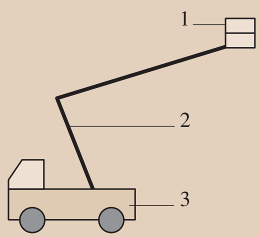


Fig. 14.80 Truck-mounted elevating platform

Table 14.10 Types of mobile elevating work platforms

Description of mobile elevating work platforms	Design schematics
A mobile elevating work platform featuring a telescopic boom. The boom can be raised, lowered, and slewed relative to the vertical axis.	
A platform mounted on a telescopic column or a hydraulic servomotor. The working motions are: the raising and lowering of the platform in the vertical plane.	
A mobile elevating platform with a scissor extending structure.	
A truck-mounted elevating platform whose extending structure is usually in the form of a two-stage boom. The elevating platform performs the following motions: • Raising and lowering • Slewing relative the vertical axis perpendicular to the base	
Key: 1 platform; 2 extending structure; 3 chassis; 4 struts	

Truck-Mounted Elevating Platform

The truck-mounted elevating platform consists of the following parts shown in Fig. 14.80.

The supporting frame is a body to which protractible struts, a hydraulic feeder, and a slewing gear are fixed. The supporting frame is secured to a truck chassis.

Table 14.11 Specifications of selected truck-mounted elevated platforms with elevation up to 15, 21, and 40 m

Specifications	Platforms with elevation of 15 m	Platforms with elevation of 21 m	Platforms with elevation of 40 m
Max. working elevation (m)	10.0–15.0	16.0–21.0	25.0–40.0
Max. horizontal radius (m)	4.2–7.4	5.5–11.0	11.6–21.9
Lifting capacity (kg)	120–200	200–300	265–365
Weight (without chassis) (kg)	950–2300	1620–5900	5200–13 400
Length in transport mode (m)	5.3–7.45	6.8–10.2	7.8–11.4
Width in transport mode (m)	1.9–2.1	2.1–2.5	2.5
Height in transport mode (m)	2.0–3.6	2.6–3.35	3.5–3.8
Slewing angle (°)	330 or 360	360	360

The slewing column is attached to the supporting frame through a crown-bearing. The column is a slewing welded-construction frame with a transmission gear and a brake mounted on it. The lower boom stage and the cylinder are attached to the column by articulated joints.

The boom consists of two stages connected by an articulated joint. Each stage is a welded box structure.

The work platform consists of a floor made from thin-walled steel sections, railings, and curbs.

The straight-line system is a tension-member structure which keeps the work platform in a horizontal position regardless of the angles at which the boom's stages are positioned.

The work platform positioning system consists of a pump, filters, distributors, valves, steel pipes, hoses, and hydraulic cylinders. The hydraulic pump is powered from the truck's gearbox via a lay shaft. Oil is supplied to the working cylinders through a rotary joint. The struts are controlled through distributors mounted on the supporting frame. The boom's cylinders and slewing can be controlled through a distributor mounted near the slewing column or on the work platform. The system is protected against the eventuality of simultaneous steering of the struts and the boom's cylinders. The boom's cylinders and those of the struts are equipped with valves to prevent a pressure failure and the resulting uncontrolled shift of the piston rod.

The maximum angle of elevation of the boom's upper stage is limited by a limit switch in the form of a hydraulic valve controlled by a cam on the boom. The hydraulic system's circuits are protected against excessive pressure rise by overflow valves.

In elevating platforms capable of large elevations (20–40 m), proportional control, ensuring that the working motions controlled by the operating lever are fluid and quick, is used instead of the typical hydraulic control.

Truck-mounted elevating platforms have the following safety measures:

- Limit switches preventing the boom's upper section from being excessively raised and the boom's lower stage from being lowered while the boom's upper stage is maximally raised
- A hydraulic system lock preventing the working circuit and the struts from being simultaneously fed
- Overload protection in the form of overflow valves

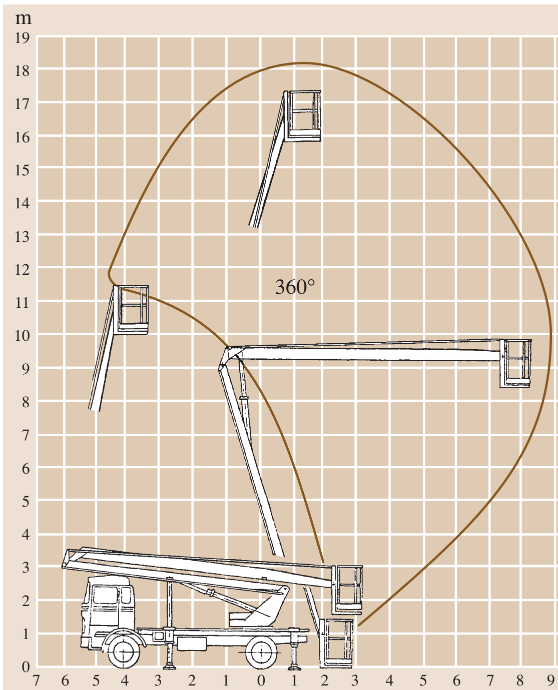


Fig. 14.81 Work area of truck-mounted elevating platform with elevation of 18 m and radius of 8.7 m

Part B | 14.5

- Emergency lowering of the cradle while the pump drive is switched off

The truck-mounted elevating platform's basic operating parameters are:

- Lifting capacity
- Maximum elevation
- Maximum radius
- Work area, specifying the allowable position of the elevating platform in the vertical plane
- Angle of rotation of the body

The work area with specified positions of the work platform in the vertical plane is shown in Fig. 14.81.

Mobile elevating platforms can be mounted on mass-produced truck chassis. The type and size of chassis depends on the specifications of the elevating platform. The characteristics of selected chassis for the particular groups are detailed in Table 14.11.

14.5.3 Hanging Scaffolds

Hanging scaffolds are intended for use in both housing and industrial construction. They are used for finishing works such as painting work, plaster work, insulation work, and window glazing. In many cases, hanging scaffolds may replace stationary construction-assembly scaffolds.

Hanging scaffolds can be divided into the following kinds:

- Stationary, hand-driven, single-person (cradle) scaffolds
- Stationary, hand- or electrically driven scaffolds
- Mobile, hand- or electrically driven scaffolds
- Stationary, hand- or electrically driven sectional scaffolds

Stationary, single-person hanging scaffolds are cradles with a single-person workstation. The cradle is suspended by a hoisting cable from a boom placed on the roof of a building. The vertical motion of the scaffold is effected by means of a two-crank hand winch operated by the person in the cradle. There are containers for materials and tools on both sides of the cradle.

A single-person hanging scaffold is shown in Fig. 14.82.

Specifications of single-person hanging scaffolds are listed in Table 14.12.

Table 14.12 Typical specifications of single-person hanging scaffold

Parameters	Value
Hoisting capacity (kg)	100
Elevation (m)	35
Hoisting speed (m/min)	1.35–2.2
Type of drive	Hand
Crank force (N)	150
Diameter of steel cable (mm)	8
Mass of movable part (kg)	148
Mass of counterweight (kg)	270

Stationary Hanging Scaffolds

These are scaffolds in which the work station is a platform with winches, suspended on cables. Hand-driven and electrically driven hanging scaffolds are used.

A stationary hanging scaffold with a hand drive is shown in Fig. 14.83.

The hanging scaffold shown in Fig. 14.83 consists of three main units: a platform, two winches with a hoisting cable, and a boom. The platform is a steel frame (lined with boards) with a take-down guardrail. The platform is equipped with roller fender beams guiding it on the building's wall during hoisting and lowering. The hanging scaffold is hoisted and lowered

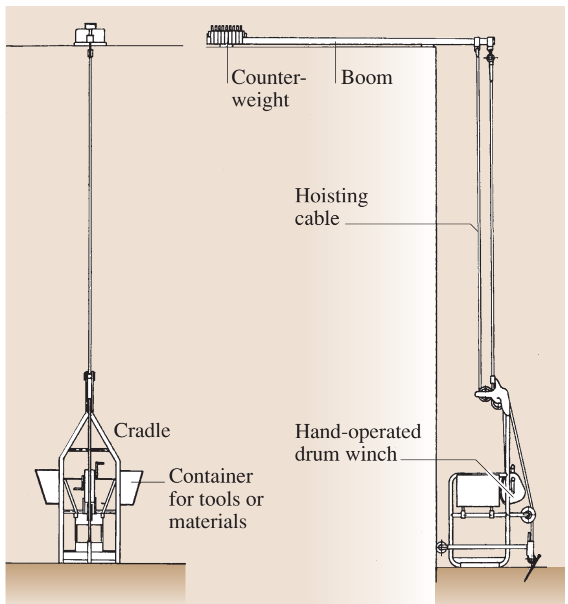


Fig. 14.82 Single-person hanging scaffold

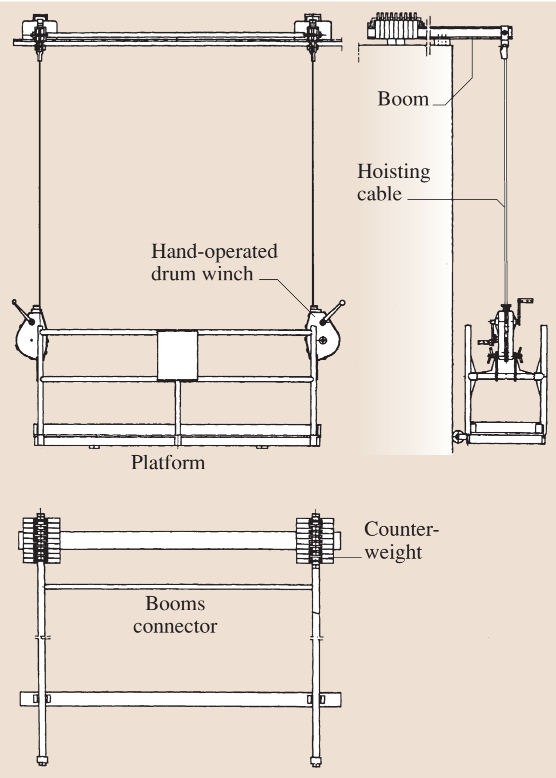


Fig. 14.83 Hanging scaffold with hand drive

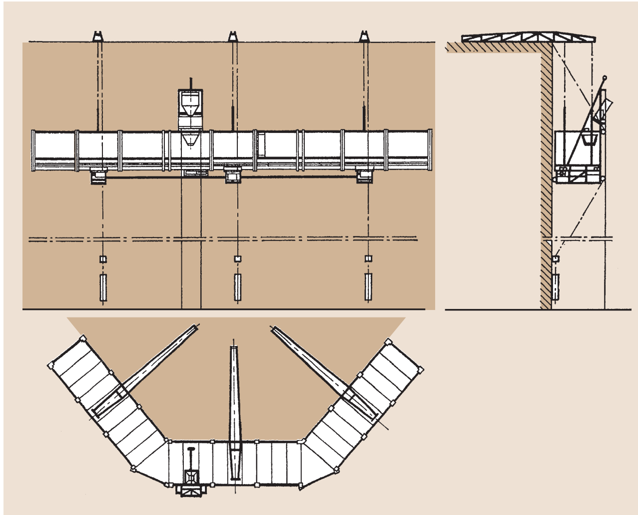


Fig. 14.85 Arched sectional scaffold. The vertical motion of the scaffolds is effected by electric motor cardan shafts and winches

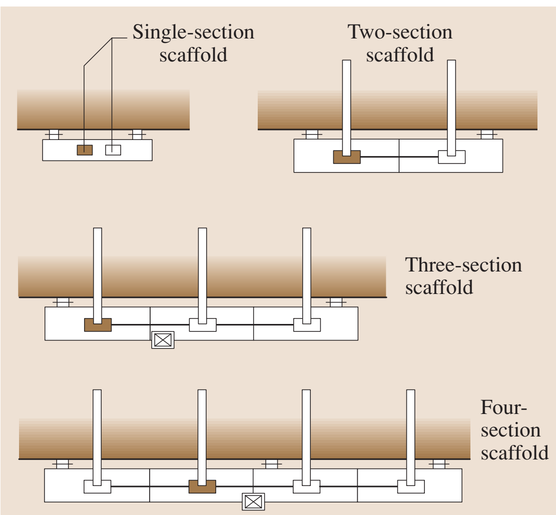


Fig. 14.84 Schematics of sectional hanging scaffolds

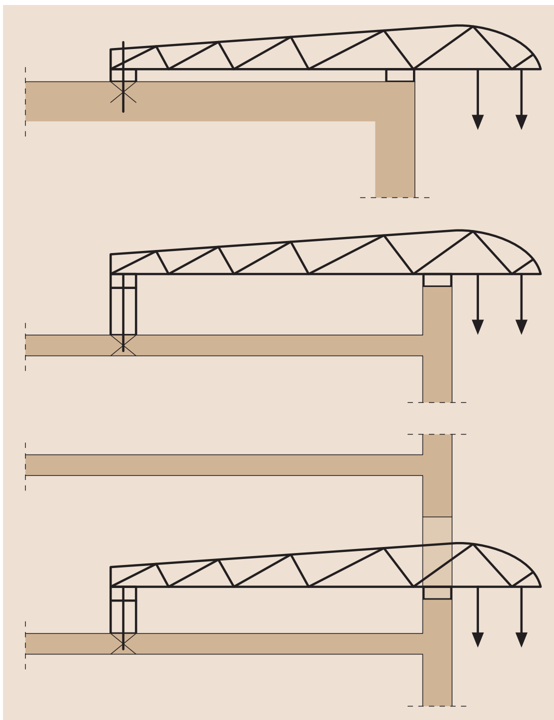


Fig. 14.86 Ways of anchoring sectional scaffolds' booms

Table 14.13 Typical specifications of hand- and electrically driven hanging scaffolds

Parameters	Hand-driven scaffolds	Electrically driven scaffolds
Hoisting capacity (kg)	300	500
Elevation (m)	up to 35	up to 80
Hoisting speed (m/min)	1.35–2.2	4–8
Crank force (N)	150	
Hoisting parameters of electric motor	–	2.2 kW (230/400 V)
Scaffold's dimensions		
Length (m)	3.0	3.1
Width (m)	0.8	1.0
Diameter of steel hoisting cable (mm)	8	11
Mass of movable part (kg)	125	620
Mass of counterweight (kg)	270	–

Table 14.14 Typical specifications of sectional hanging scaffolds with electric drive

Parameters	Scaffolds			
	1-section	2-section	3-section	4-section
Hoisting capacity (kg)	1200	1200	1200	1200
Elevation (m)	80	80	80	80
Hoisting speed (m/min)	4	4	4	4
Scaffold dimensions				
Length (m)	4.5	9.0	13.5	18.0
Width (m)	1.5	1.5	1.5	1.5
Installed power (kW)	5.5	5.5	5.5	5.5
Total weight of scaffold (kg)	900	1770	2500	3610

by means of two hand winches suspended on suspension rods and hoisting cables. The following winch types are used for hand driving hanging scaffolds:

- Typical drum winches with the end of the cable fixed to the drum
- Frictional winches with loading of the lower end of the cable by means of a weight or spring load
- Lever pull hoists

In drum winches a pawl on the winch's ratchet and a frictional mechanism prevent the scaffold from unintended descent. The scaffold is suspended from two booms joined together by pipe connectors. The scaffold is for two persons, each operating one winch during the hoisting and lowering of the platform.

A stationary hanging scaffold with an electric drive is suspended in a similar way to the hand-driven scaffold. The vertical motion of the scaffold is effected by two drum winches with gears. The turns of the winches are synchronized through a cardan shaft connection between the driving electric motor and the winches. Scaffolds of this type are equipped with a hand-operated lowering gear used in the event of failure of the electric drive.

The specifications of hand- and electrically driven hanging scaffolds are shown in Table 14.13.

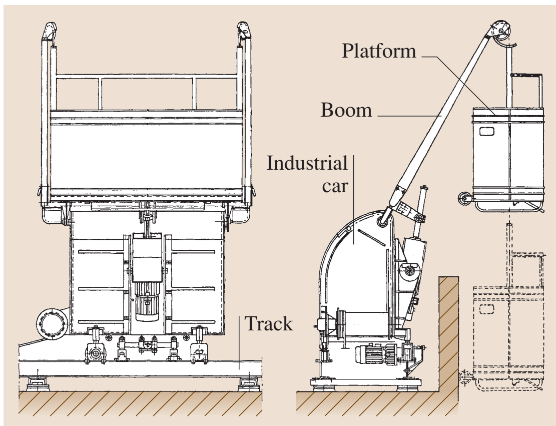


Fig. 14.87 Mobile hanging scaffold with electric drive

Stationary Sectional Hanging Scaffolds

This group includes: straight, angular, and arched hanging scaffolds, which are intended for housing and industrial construction applications, mainly facade works. Similarly to the case of the two-person scaffolds described above, the platform is suspended by steel cables from booms laid on the roof and secured with a ballast or anchored in the roof.

The scaffold consists of 3–4.5 m long 1.5 m wide segments adding up to a desired length. A schematic of the sectional hanging scaffold is shown in Fig. 14.84.

Thanks to the platform's sectional design, hanging scaffolds of different shapes (angular and arched) can be formed, as shown in Fig. 14.85.

The vertical motion of the scaffolds is effected by an electric motor, cardan shafts, and winches.

The possible ways of anchoring the booms are shown in Fig. 14.86, and the specifications of sectional hanging scaffolds are listed in Table 14.14.

Mobile Hanging Scaffolds

Mobile hanging scaffolds can be moved horizontally on an industrial car without disassembling and reassembling the booms from which they are suspended.

A typical mobile hanging scaffold design is shown in Fig. 14.87.

The vertically moving work platform is suspended by steel cables from booms mounted in a swinging mode on an industrial car. Drives for traveling on a track laid on the roof of a building and for hoisting the platform are installed on the industrial car. The scaffold can be steered from both the platform and the roof. Scaffolds of this type usually have a hoisting capacity of about 300 kg and are capable of an elevation of 100 m.

14.6 Cranes

14.6.1 Mobile Cranes

Mobile cranes are intended for lifting and lowering loads and transferring them in the horizontal plane [14.23, 32]. Mobile cranes find wide application in the assembly of steel and reinforced concrete structures, repairs and materials handling. Their advantage is their mobility, high traveling speed, and quick setup on a construction site.

As regards their undercarriage, mobile cranes are divided into:

- Truck cranes
- Terrain-wheeled cranes
- Crawler cranes

Mobile cranes are typically truck-mounted. Cranes with a maximum lifting capacity of up to 20 t are usually mounted on mass-produced truck chassis, whereas high-capacity cranes are mounted on special undercarriages. The latter may have all their wheels driven and turnable, making them highly manoeuvrable and able to move over rough terrain.

Modern hydraulically driven cranes have replaced cranes with mechanical and pneumatic steering. A modern truck crane with electrohydraulic drives and steering is shown in Fig. 14.88.

The crane's base is a frame which, depending on the crane's design and hoisting capacity (maximum 20 t), may constitute a separate subassembly mounted on a typical truck chassis or be an integral part of a special truck chassis (high-capacity cranes). Mobile cranes are usually driven by internal-combustion engines, although some terrain-wheeled cranes and their working tools are driven by hybrid combustion–electric drives. In high-capacity cranes usually two driving motors are used: one for driving the vehicle and the other (situated in the slewing body) for driving the working tools.

The crane's frame incorporates four struts, with hydraulic lifts attached to their ends, extended by two hydraulic servos. For work the struts are protracted horizontally and then the whole crane is jacked up by the hydraulic lifts to such a height that the road wheels do not touch the ground. Some cranes can operate on their road wheels.

The slewing body with the operator's cabin is connected with the chassis frame through a crown bearing. All the working fittings are mounted on the crane body. The jib consists of a stationary section and two to six protractible sections. The jib's sections are usually protracted synchronously. The winch is mounted at the origin of the telescopic jib's stationary section. A significant number of cranes are equipped with an auxiliary jib which in its working mode can be attached to the telescopic jib's head in order to increase the crane's radius. In the traveling mode the auxiliary jib is attached to the side of the permanent telescopic jib. A counterweight is mounted at the rear of the slewing body.

The principal working gears and systems of telescopic-jib cranes are:

- *A jib-protracting gear* driven by two reversible hydraulic cylinders. As a rule, the jib's members are protracted synchronously.
- *A crane radius changer* driven by a reversible hydraulic cylinder. In high-capacity cranes sometimes two hydraulic cylinders are used for this purpose. The crane radius changer typically allows one to set the jib at an angle of 0–75°.
- *A slewing gear* driven by a hydraulic engine, a planetary gear, and a crown bearing with outer meshing. The slewing gear is equipped with an automatically controlled multiple disk brake.
- *A lifting gear* consisting of cable drum winch, a cable, pulleys, and a pulley block. The cable drum is driven by a hydraulic engine and a planetary gear. As a rule, the winch's pull force is much weaker than the crane's maximum lifting capacity. Hence it is necessary to use multistrand blocks to reduce the forces in the cable.

All the working gears and the gear that extends the struts are hydraulically driven. In truck-mounted low-capacity cranes equipped with one internal-combustion engine, the hydraulic oil tank and the hydraulic pumps are mounted in the crane's undercarriage. Hydraulic oil is fed into the body's working circuits through a hydraulic rotary joint. In cranes with two internal-combustion engines, the hydraulic pumps of the crane's working circuits are driven by the engine mounted in the slewing body.

The following working motions of the crane are controlled:

- Body slewing
- Change of jib length
- Inclination of jib
- Lowering and raising of the hook
- Traversing gear motions (for terrain crawler cranes and some wheeled cranes in which traveling with a load suspended from the hook is allowable)

These working motions are typically controlled from the operator's cabin. A system of control levers, which can limit the linking of the particular working motions, ensures proper control of the latter. The recommended systems and directions of motion of the control levers are shown in Fig. 14.89.

All cranes are equipped with the following safety devices:

- *A load limiter* – usually a microprocessor unit signalling that the hook block is reaching the rated load and disabling the crane's working motions when the rated load is exceeded. A signal indicating that the hook block is approaching the rated load is activated at 0.9–1.0 of the nominal load: an orange indicator light comes on in the control panel in the operator's cabin and an audible warning is produced. Overload is signalled by a red indicator light and disabling of the working motions, except for downward motion of the lifting gear. The signalling system is activated and motions are disabled when the crane block load is in the range of 1.0–1.1 of the rated load. The load limiter should be calibrated for a given hoisting capacity characteristic. Each load limiter should be equipped with an interlock for disabling the limiter in an emergency:
- *A block upper position limit switch* – disengages the winch's drive when the block finds itself at a certain distance from the jib's head.
- *Slewing gear limit switches* – are used in cranes that cannot turnaround completely, e.g., an allowed rotation angle of 270°. These protect the crane against the situation in which the slewing column and the jib reach an out-of-specification position relative to the chassis.
- *Cable unwinding limit switch* – protects against complete unwinding of the cable from the winch drum. The limiter is actuated when there are only a few coils of cable left on the drum.
- *Emergency jib retracting and lowering system* – enables the retracting and lowering of the jib to a safe position in the case of a failure of the hydraulic system.
- *Hydraulic system protections* – enables the automatic return of the piston rods of the struts', the radius changer's, and the lifting gear's cylinders.

The basic parameters characterizing the operating properties of mobile cranes are:

- Hoisting capacity
- Radius
- Hoisting height

The values of these parameters are usually presented in the form of diagrams representing hoisting

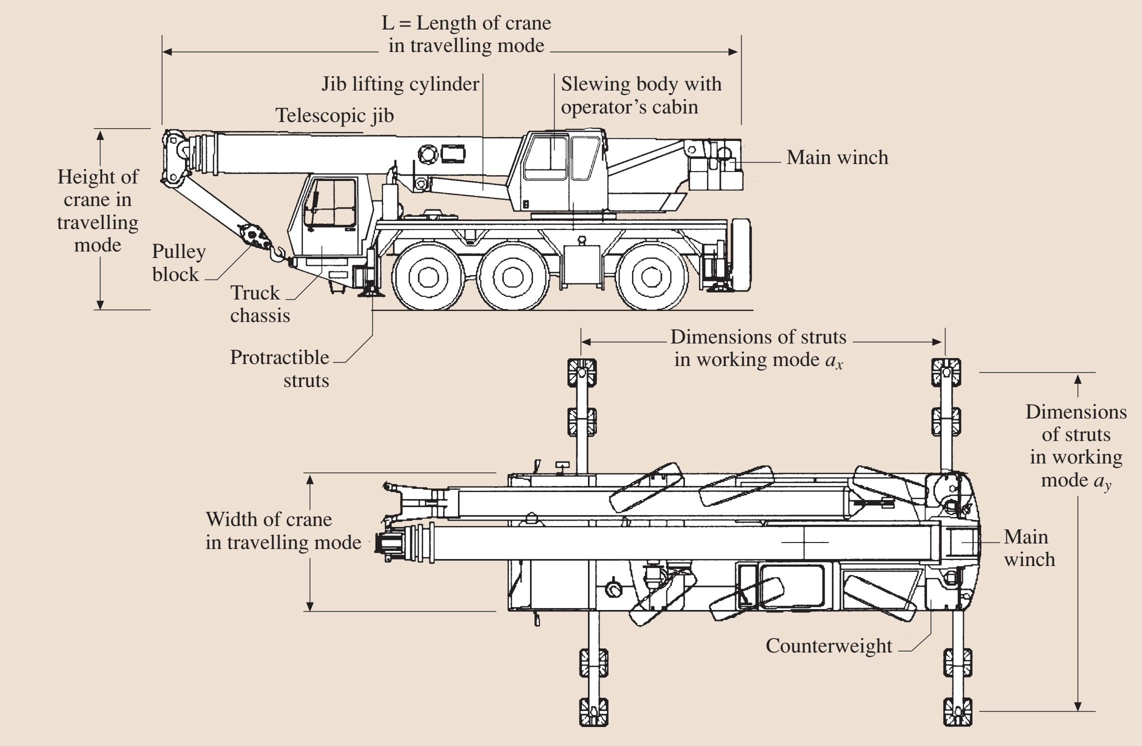


Fig. 14.88 Mobile crane mounted on a special truck chassis in traveling mode (a_x and a_y dimensions of struts in working mode)

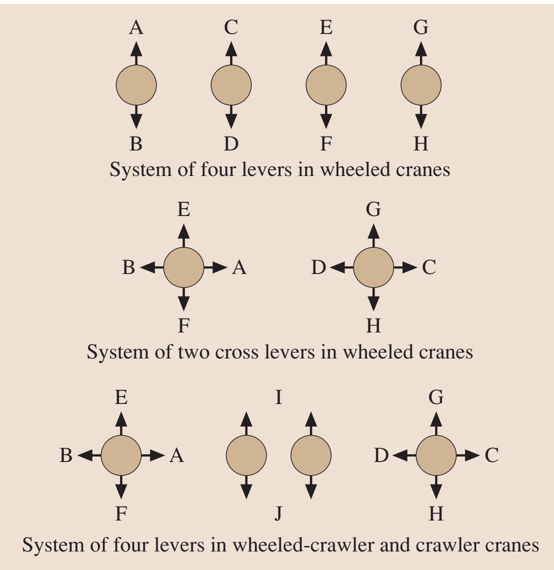


Fig. 14.89 Systems and directions of control lever motions in mobile cranes

capacity versus radius and jib length. Exemplary diagrams for truck-mounted mobile cranes are shown in Figs. 14.95–14.98.

Hoisting capacity diagrams specify calculated and experimental crane load values which take into account the crane's position stability and its structural strength.

Mobile cranes very considerably in their basic operating parameters. The hoisting capacity of currently manufactured cranes ranges from 5 to 550 t. Their basic specifications are listed in Table 14.16.

When selecting a crane for a given range of works one should consider the following:

Table 14.15 Symbols used in Fig. 14.89

A	–	turn right	G	–	lower hook
B	–	turn left	H	–	raise hook
C	–	protract jib	I	–	travel forwards
D	–	retract jib	J	–	travel backwards
E	–	increase radius	F	–	decrease radius

- The maximum hoisting capacity is given for the retracted main jib and a small radius of about 3 m and so is of little practical value. Hoisting capacity at larger radii decreases markedly.
- One should aim at operation at the smallest possible radii and hoisting heights so that a rational choice of a crane can be made and the crane's useful properties be effectively exploited. The use of large radii and hoisting heights should be technologically justified.
- One should take into account the travel of the crane to the working area and the bearing capacity of the ground on which the crane is to be set up. The bearing capacity of the ground should be appropriate for the anticipated loads acting on the struts.

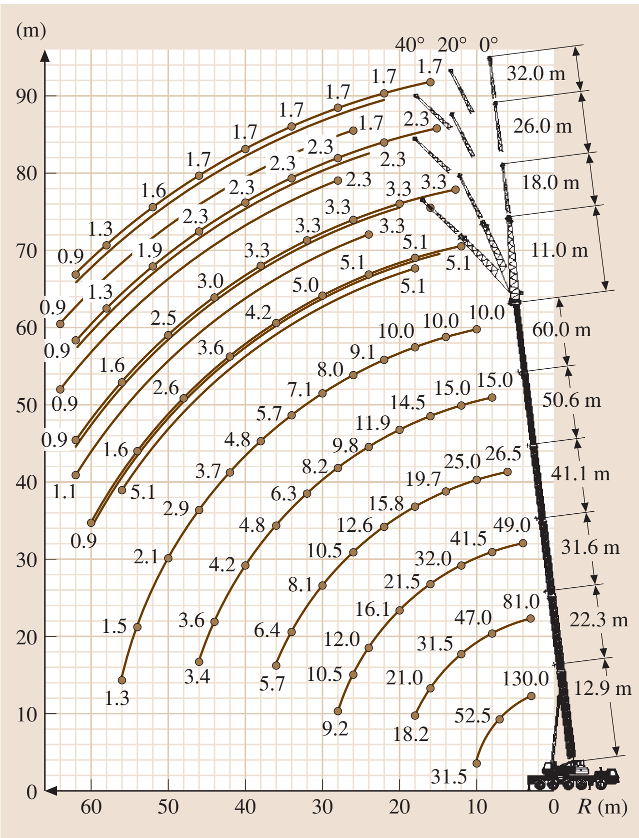


Fig. 14.91 Diagram representing hoisting capacity of crane with maximum capacity of 130 t. Note: The characteristic is determined for the main jib and the auxiliary jib. The *numbers* above the curves specify the allowable hoisting capacity for a given jib and hoisting height

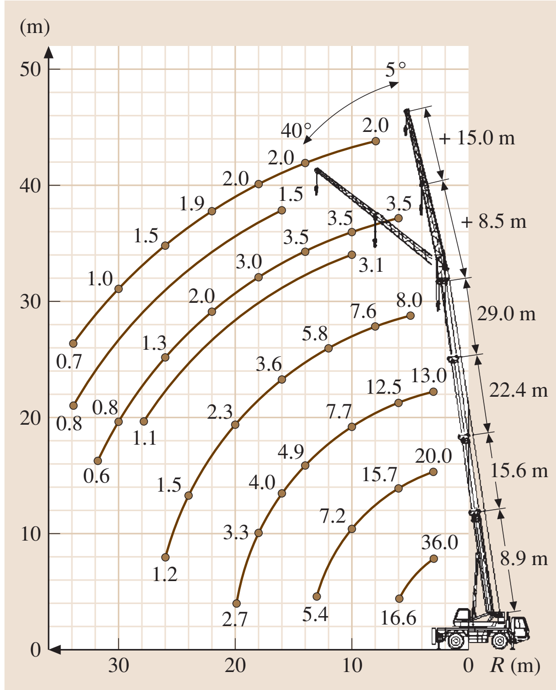


Fig. 14.90 Diagram representing hoisting capacity of crane with maximum capacity of 35 t. Note: The characteristic is determined for the main jib and the auxiliary jib. The *numbers* above the curves specify the allowable hoisting capacity for a given radius and hoisting height

14.6.2 Small Capacity Portable Cranes, Gantries, and Winches

A range of portable machines, based on winches and other accessories, for handling materials and transferring light equipment on construction sites has been developed.

This machinery includes:

- Scaffold cranes mounted on scaffolds (Fig. 14.92 items 5 and 6, and Fig. 14.95)
- Portable cranes (Fig. 14.92 item 4, and Figs. 14.96, 14.98) fixed to steel supports installed between floors, in window openings or on the roof (Fig. 14.97, basic parameters are shown in Table 14.17)
- Gantries mounted on the roof (Fig. 14.92 item 3), in an opening in the building's elevation (Fig. 14.92 item 2) or on a scaffold (Fig. 14.89 item 1)

The main component of the above machines is a universal winch that can work in tandem with various accessories.

Figure 14.92 shows the use of scaffold cranes, portable cranes, and small-capacity gantries during building erection.

Machinery of this type is intended for lifting and transferring loads of up to 200 kg to a height of 80 m. The design and technical specifications of these winches make them a highly effective means of vertical transport in construction work involving scaffolds as well as the assembly and disassembly of scaffolds.

Winches in scaffold cranes can be mounted in two ways:

- Outside the crane, to the lowest (from the ground) scaffold upright (Fig. 14.93)
- On the crane's boom (Fig. 14.92 item 5, and Fig. 14.94)

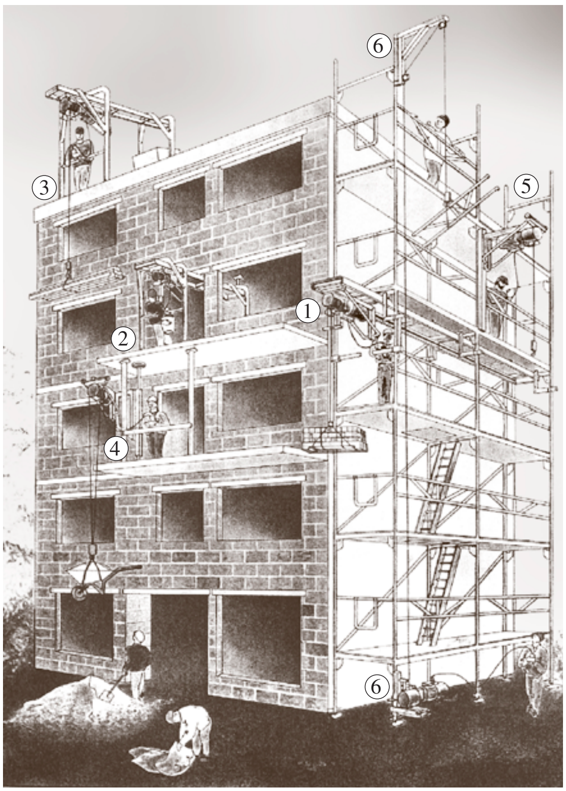


Fig. 14.92 Use of scaffold cranes, portable cranes, and small-capacity gantries during erection of building (items 1–6 are explained in the text)

In the case of winches mounted using the former method, a limit switch, functioning also as a load limiter and a block upper position switch, is incorporated into the winch's housing.

The way in which a winch is mounted onto the boom is shown in Fig. 14.94 and Fig. 14.92 item 6.

The working radius of the boom with a mounted winch can be changed by protruding the load-bearing tube. There is a series of holes in the inner tube for a blocking pin. The boom with the winch can be attached in a slewing mode to all kinds of support elements (Figs. 14.95–14.98).

The advantage of winches mountable on booms is their simple design and assembly owing to the

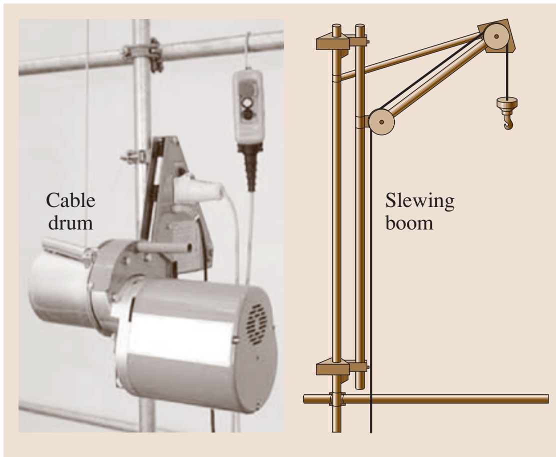


Fig. 14.93 Scaffold mountable winch

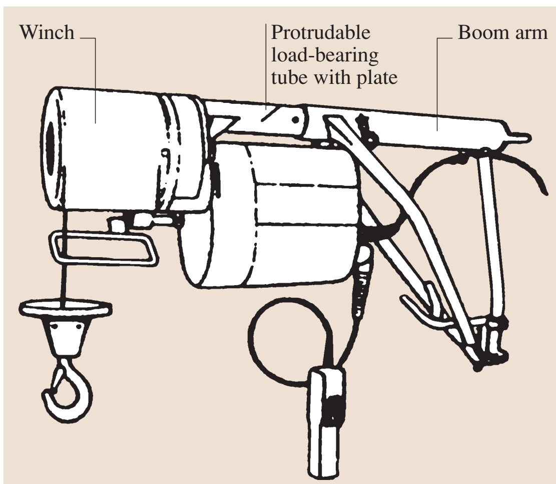


Fig. 14.94 Winch mounted on boom

Table 14.16 Specifications of selected mobile cranes with telescopic jib

Rated hoisting capacity	8	25	50	90	130	450
Minimum radius of main jib (m)	3	3	3	3	3	3
Maximum radius of main jib (m)	12	26	34	37	56	56
Jib's angle of inclination (°)	0–75	3–82	3–82	3–82	3–82	3–82
Cable winding speed (m/min)	42	130	120	125	120	130
Dimensions in traveling mode (mm)						
• Length	9050	10 225	11 020	12 795	14 980	19 622
• Width	2500	2500	2500	3000	2750	3000
• Height	3500	3450	3480	3795	3910	3990
Spacing between struts						
a_x (mm)	4450	6325	6625	8100	7800	8760
a_y (mm)	4136	6200	6200	7000	7500	8900
Maximum traveling speed	40	75	85	79	80	85

elimination of intermediate cable pulleys. Their disadvantage is the unfavorable weight and load distribution along the boom's end, resulting in the increase in the forces needed to slew the loaded boom and in heavier loading of the load-bearing structure.

The structure of winches with a hoisting capacity of 60–200 kg, employed in portable cranes and gantries, is shown in Fig. 14.99. The characteristic feature of such winches is the use of an electric motor with a built-in brake and the integration of all the units, i. e., the electric motor, the toothed gear, the drum, and the electric control system.

The drive units of modern winches commonly incorporate:

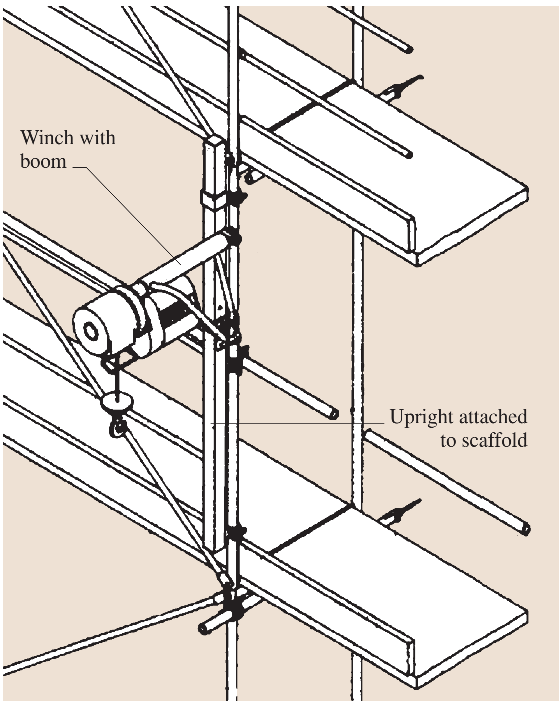


Fig. 14.95 Scaffold crane

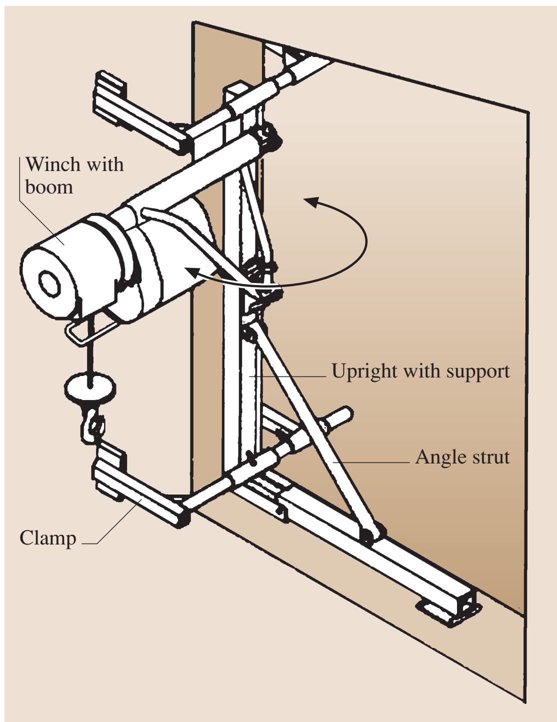


Fig. 14.96 Portable crane mounted in window opening

- Clutchless connection between the motor and the gear transmission – a gear wheel interacting with the transmission gear's toothed wheel is mounted in the rotor shaft's end.
- The cable drum is equipped with bearings internally whereby the transmission and the cable drum are compact.

Modern winches are intended for vertical transport for a wide range of construction works. Hence the range of handled construction materials is highly diverse as regards kind, shape, dimensions, and so on.

For this reason the manufacturers of light cranes offer a wide range of accessories for securing the load. Examples of accessories for handling different kinds of materials are shown in Fig. 14.100.

The use of such elements greatly increases work effectiveness and improves operational safety.

14.6.3 Tower Cranes

General Information

Tower cranes are commonly used in civil engineering for short-distance transport of loads and for erecting reinforced-concrete, steel, and masonry structures. Tower cranes owe their universality to the ease with which their structural-operating specifications (hoisting height, radius, and lifting capacity) can be adapted to the needs of construction sites. Such adaptation is possible thanks to the modular structure of tower cranes.

Tower cranes are classified according to the design of their basic units, e.g., the kind of slewing gear, the method of relocating and setting up, the jib design, and the tower design.

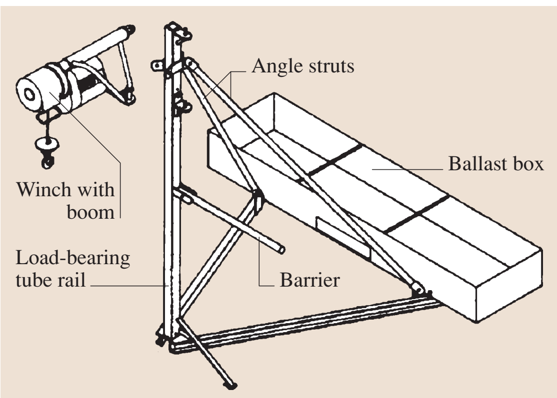


Fig. 14.97 Portable crane mounted on building's roof

Table 14.17 Technical specification of portable cranes

Lifting capacity	60–200 kg
Boom's radius (accessories)	About 1 m
Lifting height (max)	75–80 m
Lifting speed – first gear	15–20 m/min
Lifting speed – second gear	40–60 m/min
Accessories boom slewing	Manual
Power supply	230 V single-phase AC
Motor's power	0.3–1.1 kW
Control	Control panel
Drive unit mass	35–60 kg

According to the slewing gear design, two kinds of tower cranes: *high-* and *low-slewing* (with a non-slewing tower and a slewing tower) can be identified. The typical components of *high-slewing tower cranes* are: a stationary vertical tower resting on a base or a foundation anchor and a slewing part consisting of a rotary ring, a turret, a jib, and a counterjib. The typical components of *low-slewing tower cranes* are a slewing vertical tower resting on a base and a jib.

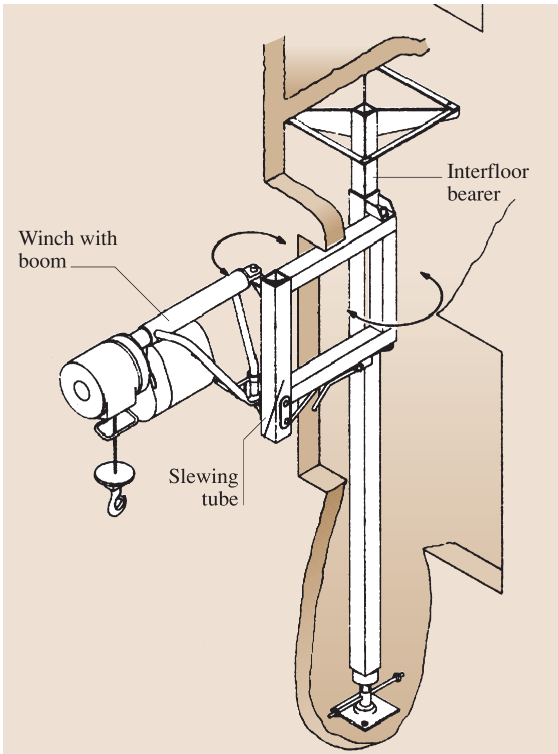


Fig. 14.98 Portable crane fixed to steel support

Each tower crane mounted on a base can be additionally equipped with a traversing gear to enable it to move on a straight or curvilinear track.

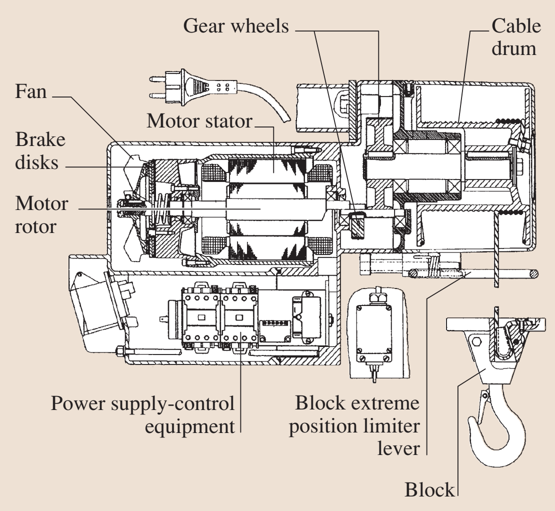


Fig. 14.99 Structure of winch used in portable and scaffold cranes and small-radius gantries

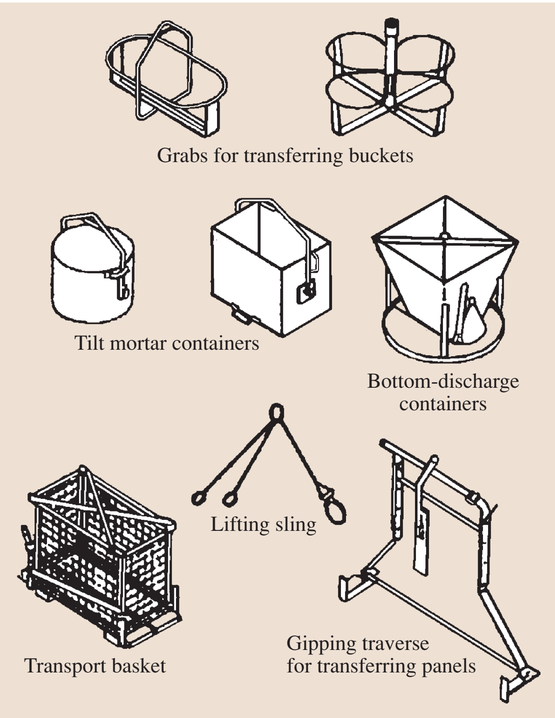


Fig. 14.100 Examples of accessories for handling materials by portable cranes, gantries, and winches

The tower and jib of modern cranes have a modular design. The tower's height and the jib's length can be adjusted by changing the number of tower or jib modules (sections). As a result, the basic operating specifications of tower cranes (hoisting height, radius, and hoisting capacity) vary greatly, not only within the particular kinds of cranes but also within a given crane model.

The main operating specifications of the most common type of cranes, i. e., *high-slewing cranes*, are as follows:

- Autonomous hoisting height: up to 100 m (at a 2.45 m × 24.5 m tower cross section)
- Maximum hoisting capacity: 50 t (4–16 t in housing construction)
- Radius: 20–80 m

Besides the above most common cranes, there are also cranes made to order, e.g., a crane with a hoisting capacity of 225 t, a radius of 80 m, and a hoisting height of 130 m. The crane is equipped with a computer system that controls the position of the jib counterweight to counterbalance the bending moments acting on the tower and it has a lift for transporting the operator to the control cabin.

The basic operating specifications of *low-slewing cranes,* as an option, are as follows:

- Maximum hoisting height: up to 50 m
- Maximum hoisting capacity: 2–8 t
- Radius: 10–50 m

Most of the currently manufactured *low-slewing trolley cranes* can operate with the jib raised at a certain angle (usually 8–30°).

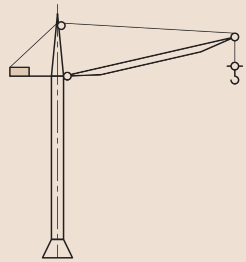
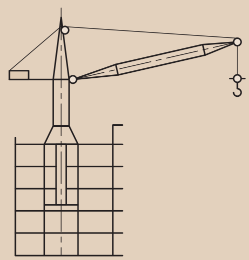
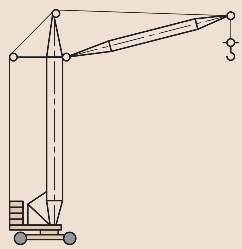
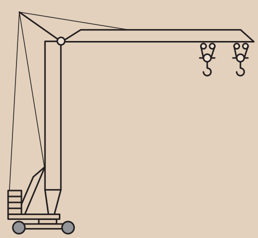
A classification of tower cranes according to their design features such as:

- Movability relative to the erected building structure
- Jib design
- Tower design

is detailed in Tables 14.18–14.20.

Cranes with a horizontal trolley jib are most commonly used in construction. Cranes with inclinable jibs find many fewer applications; they are used mainly on construction sites with restrictions on the crane's work radius because of the site's location and its organizational-legal conditions (e.g., in places where charges for the area over which the crane's jib passes are levied).

Table 14.18 Classification of tower cranes according to their movability

Type of crane	Description	Sketch
Stationary crane	Mounted on foundation anchor	
Floor crane (moving up with erected building structure)	Mounted on erected building structure and jacked up as successive storeys are built	
Track crane (moving on track)	Mounted on base equipped with traversing gear enabling traveling on track	
Mobile	Truck-mounted or wheeled, partially or fully folded during transport	

Cranes with Trolley Jib

As mentioned above, tower cranes with trolley jib are currently most commonly used on construction sites. A typical design of such a crane is shown in Fig. 14.101.

The crane's structure consists of basic units: a base, a tower, a slewing head, and a jib.

Base. Depending on the site's requirements, the crane's base can also be mounted on:

Table 14.19 Classification of tower cranes according to jib design

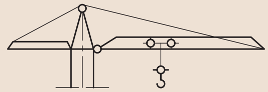
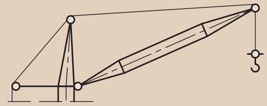
Type of crane	Description	Sketch
Crane with horizontal trolley jib	Jib operating in horizontal plane; radius is changed through movement of trolley along jib; jib can be attached to tower with or without tie rods. In some cranes, jib can be raised at angle of 8–30°	
Crane with inclinable jib (without trolley)	Jib can be inclined in vertical plane; radius is changed through inclination of jib	

Table 14.20 Classification of cranes according to tower design

Name of crane	Description
High-slewing tower cranes (cranes with nonslewing tower)	Crane's tower does not slew. Jib can slew thanks to slewing towerhead connected with tower via rim bearing
Low-slewing tower cranes (cranes with slewing tower)	Crane's tower slews. Tower is connected to crane's base via rim bearing

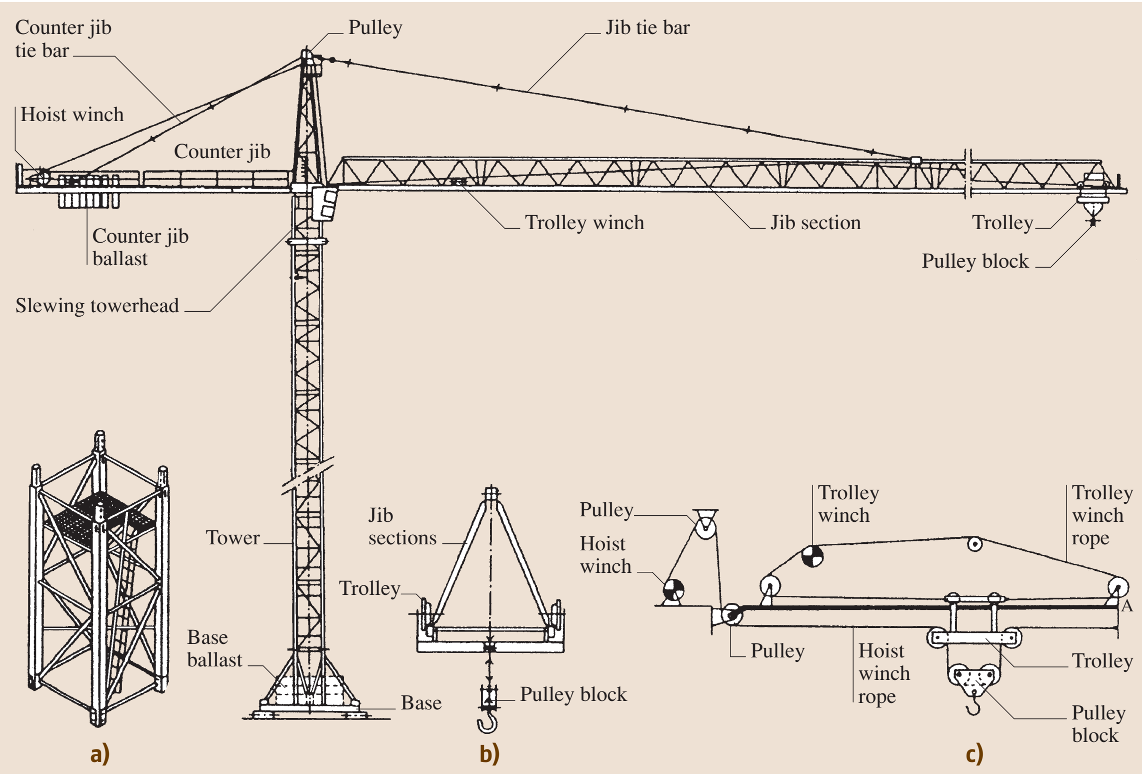


Fig. 14.101a–c Tower crane with trolley jib – main parts. **(a)** Tower's section. **(b)** Jib and trolley's cross section. **(c)** Kinematic diagram of trolley and pulley block winch hoist drive

- Supports provided with foundation plates (Fig. 14.102a)
- Trucks traveling on a rail-track (Fig. 14.102b)
- Supports on a concrete foundation (Fig. 14.102c)
- Feet embedded in foundation concrete (Fig.14.102d)

In most modern high-slewing cranes, the tower can be also mounted directly on the building structure being erected and goes up with it. For the assembly and disassembly of cranes three special frames are used. The tower is fixed by means of two frames to the erected building structure's members (usually a floor) (Fig. 14.103). A third frame is used to jack the crane up to a higher storey.

The *tower* is a metal structure usually in the form of a space truss with columns open or closed in cross section. The tower functions as a support for the jib which can be mounted on it at the appropriate height. In cranes with a nonslewing tower, a head is attached, via a rim bearing, to the tower's top. The tower is made as a welded construction or from sections joined by fasteners. Typically, 2.8–6 m-high (for the telescopic self-erecting model) sections square in their cross section or 6–12 m-high (for a crane set up using a truck crane) ones are used. The sections are fastened together with bolts or pins. In high-slewing cranes, a slewing head is mounted onto the stationary tower's top and a jib and a counterjib (with its ballast) are attached to it. The slewing head assembly usually incorporates a slewing gear drive.

In most cranes, the height of the tower can be increased without it being necessary to partially disassemble the crane. This is done using a telescopic cage by means of which the crane can be raised and additional tower sections can be inserted.

The *jib* is a space framework fixed to the tower (slewing-tower cranes) or a slewing towerhead (nonslewing tower cranes), making it possible to obtain a proper radius through the shift of the trolley. Jibs usually consist of several sections to facilitate their transport and assembly. The trolley moves on the jib's bottom flanges (Fig. 14.101b).

Pulley block hoisting gear. A hoist winch rope (Fig. 14.101c) passes from the hoist drum (Fig. 14.101c) via two pulleys (Fig. 14.101c) attached to the tower and then along the jib (Fig. 14.101) through the trolley (Fig. 14.101c) and the pulley block (Fig. 14.101c) to a securing point (Fig. 14.101c) at the jib's tip. As the rope winds on (unwinds from) the hoist drum, the pulley block is raised or lowered.

Trolley traversing gear. The trolley is shifted along the jib by a closed rope system (Fig. 14.101c) driven by a hoist winch (Fig. 14.101c).

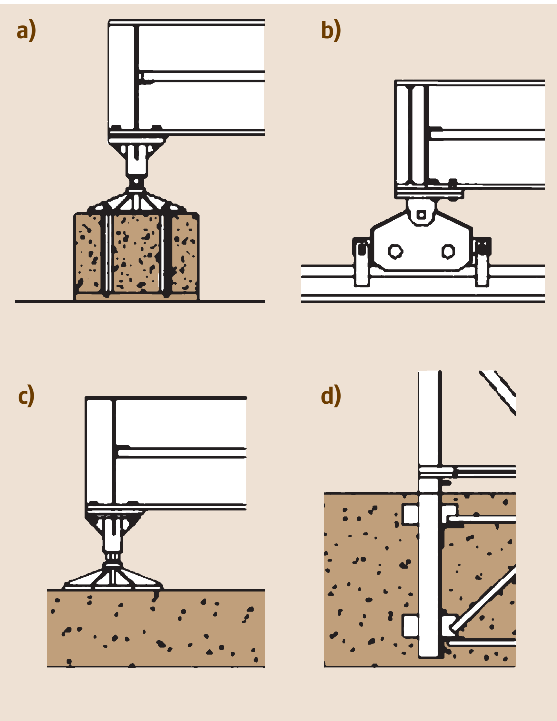


Fig. 14.102a–d Alternative ways of mounting tower crane with trolley jib **(a)** on supports provided with foundation plates; **(b)** on rail trucks (mobile version); **(c)** on supports and foundation plate; **(d)** on feet embedded in foundation concrete

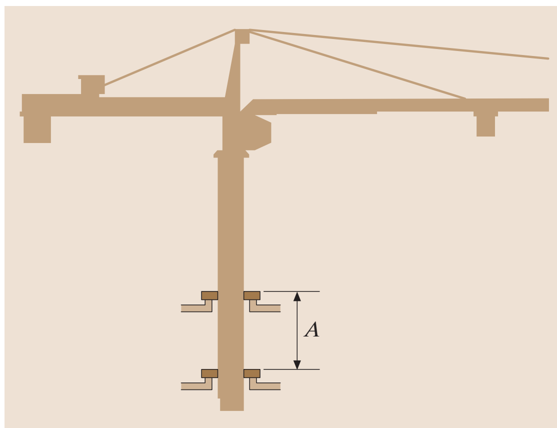


Fig. 14.103 Way of fixing tower to structural members of building under construction

Table 14.21 Technical operating specifications of typical 8–40 t hoisting capacity cranes

Parameter	Tower crane with maximum hoisting capacity of				
	8 t	10 t	12 t	25 t	40 t
Maximum hoisting height (m)	71	71	69	93	80
Maximum radius (m)	60	65	70	80	80
Maximum speed of hoisting two-suspender pulley block (m/min)	46 (4 t) 124 (1 t)	36 (5 t) 96 (1.25 t)	30 (6 t) 78 (1.5 t)	0–34 (10 t) 80 (2.5 t)	40 (20 t) 96 (2.5 t)
Minimum speed of hoisting two-suspender pulley block (m/min)	4	3	2.4	–	–
Trolley traversing speed (m/min)	0–76	0–50 (10 t) 0–100 (5 t) 0–120 (2.5 t)	0–50 (12 t) 0–100 (6 t) 0–120 (3.0 t)	0–47 (25 t) 0–63 (12.5 t) 0–76 (6.25 t)	0–33 (40 t) 0–50 (20 t) 0–100 (2.5 t)
Max. slewing speed of jib (rpm)	0.8	0.8	0.8	0.8	0.8
Possible ways of crane mounting	A, B, C, D	A, B, C, D	A, B, C, D	A, B, C, D	A, B, C
Tower section length (m)	3.3/5/10	3.3/5/10	3.3/5/10	3.3/5/10	3.3/5/10
Jib section length (m)	5/10	5/10	5/10	5/10	5/10
Load characteristic for max. jib length	Fig. 14.90 curve for 8 t crane	Fig. 14.90 curve for 10 t crane	Fig. 14.90 curve for 12 t crane	Fig. 14.91 curve for 25 t crane	Fig. 14.91 curve for 40 t crane

Legend:
A – base mounted on feet
B – base with suspension system enabling traveling on rail-track
C – tower mounted directly on feet embedded in foundation concrete
D – mounted on building structure under construction and jacked up as successive storeys are erected

A hoisting speed proper for the hoisting capacity is selected by a remote-controlled gear switch. The speed can be as high as 125 m/min. The maximum trolley traversing speed is 80 m/min. The pulley block hoisting gear and the trolley traversing gear are driven by squirrel-cage motors or slip-ring motors equipped with electromagnetic brakes. Hydrostatic drives or electric motors with controlled speed are also used.

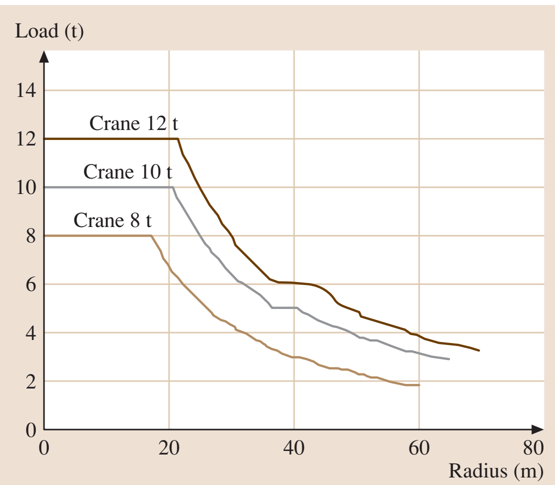


Fig. 14.104 Load–radius curves for 8 t, 10 t, and 12 t cranes

The crane's work motions are controlled from the operator's cabin using the controllers installed there, or they are radio-controlled. The operator's cabin can be equipped with a hoisting gear by means of which it can be hoisted to the appropriate height.

In the case of track-mounted (mobile) cranes, trackways made from traffic rails, (wooden or concrete) sleepers, ties, and stops, laid on a subgrade, are used. The track can be laid on a soil subgrade or a structural subgrade (a support structure, a building floor, a hard road surface). Usually railway rails are used for the tracks. The rails should be fixed to sleepers laid on a subgrade. The tracks should have protective groundings and lightning conductors. The tracks are equipped with the following protections:

- *Stationary and movable bumping blocks*: Stationary bumping blocks are usually situated at a distance of 1.5 m from the end of the track rails and movable bumping blocks at a distance of 1.2–1.5 m from the stationary ones.
- *Travel stops*: Devices switching off the crane's traversing gear when the gear's tripper runs into

a cam. Cams are mounted at the end of the crane track before the movable bumping blocks. The cams are positioned in parallel to the track so that the lever of the traversing gear tripper mounted on the crane's carriage can run into them.

After work, mobile cranes are secured to the trackway by means of clamps (fastening the carriage to the rails) preventing wind pressure from shifting the crane from its work position.

Tower cranes are equipped with the following protections:

- *Hoisting capacity limiter*: A device protecting the crane from lifting too heavy a load for a given radius. The protection acts in two stages. The reaching of the nominal hoisting capacity or moment is signalled acoustically and visually starting at 90% of the nominal values. The loading of the crane with a load amounting to 100–115% of the nominal hoisting capacity or with a moment amounting to 100–125% of the nominal moment results in the shut down of all the drives of all the gears except for the hoisting gear's lowering function. Each load limiter should have an interlock so that it can be switched off in an emergency situation.
- *Moment limiter*: Functions similarly to the hoisting capacity limiter.
- *Pulley block top hoisting position tripper*: Shuts down the hoisting winch's drive when the pulley block comes very close to the jib's trolley.

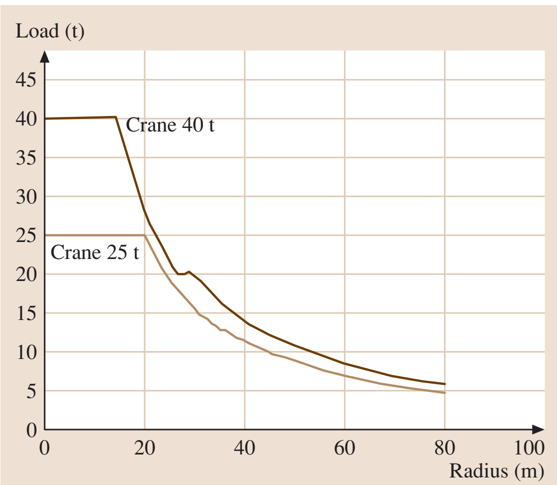


Fig. 14.105 Load–radius curves for 25 t and 40 t cranes

- *Rope unwinding tripper*: Prevents the rope from unwinding completely from the hoisting drum. The tripper is activated when only a few coils of rope are left on the drum.
- *Trolley extreme position tripper*: Stopping the traversing of the trolley in one direction in its extreme positions.
- *Slewing tripper*: Stops the slewing motion of the crane when the crane's angle of rotation in one direction exceeds 1.5 turn (540°) to prevent the machine's feeder cables and control cables from being damaged (this applies to cranes without a rotary joint enabling unlimited slewing).

Since there is a wide range of tower cranes with a horizontal trolley jib, one can select the crane best suited to the construction site's conditions. It is common practice that several tower cranes with different hoisting elevations and capacities are so arranged around the structure under construction that they are complementary to one another. In such cases, particularly when the cranes' work areas overlap, it is extremely important that their simultaneous work is properly synchronized.

The basic structural-operating specifications of 8–40 t hoisting capacity cranes are shown in Table 14.21. For small radii the parameter which lim-

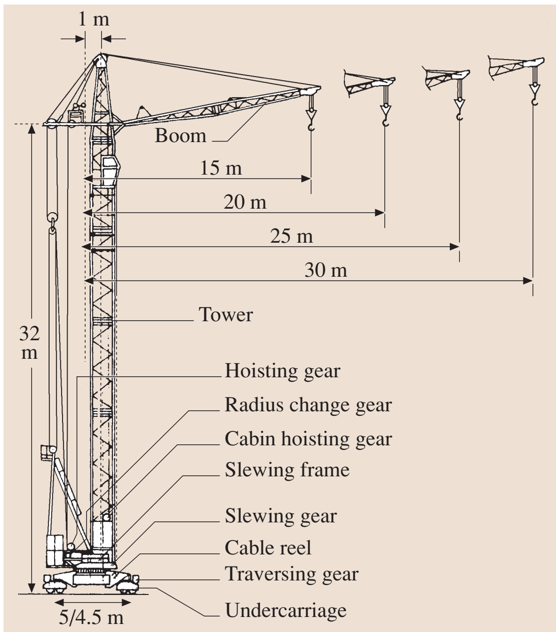


Fig. 14.106 Track tower crane with 10 t hoisting capacity with luffing boom

its the hoisting capacity of a tower crane is the strength of the load-bearing structure, while for larger radii the decisive parameter is the crane's stability. The crane's hoisting capacity characteristics specify the safe load values, calculated and experimentally determined taking into account the crane structure's stability and strength.

The load–radius curves for 8–40 t cranes are shown in Figs. 14.104 and 14.105.

Cranes with Luffing Boom

The structure of tower cranes with a luffing boom is described below using as an example a 10 t hoisting capacity track crane with a slewing tower (Fig. 14.106).

The crane's undercarriage consists of a welded box frame and cantilevers for mounting rail trucks. The undercarriage enables travel on straight and arched tracks. A rotary ring is attached to the undercarriage frame. A slewing frame with a hoisting gear, a radius changer, a slewing gear, and concrete ballast plates is mounted on the ring. The crane's tower and an installation cantilever are fixed to the slewing frame. The tower consists of segments, usually made from angle bars or steel pipes. An operator's cabin is attached to the tower, to which access is provided by a ladder secured to the tower. The crane's boom and a guy rope are attached to the tower's top segment. The boom is a welded lattice structure, quadrangular or triangular in cross section, made from high-strength steel sections. The boom consists of several sections (typically three ones) joined together by bolts. Cable pulleys, a hoisting gear tripper, and an overload tripper are mounted on the boom tip.

The crane's particular working motions are executed by the hoisting gear, the radius change gear, the tower slewing gear, and the traversing gear.

The hoisting gear consists of a motor, a coupling, a brake disk, a reduction gear, and a cable reel. Hoisting speed is changed by means of the reduction gear ratio lever. An additional drum for installing concrete counterbalance elements, is mounted on the hoisting gear's shaft.

The radius change gear consists of a hoisting winch and rigging. Drive is transmitted from the winch's motor via the flexible coupling working together with the brake and a thrustor to the reduction gear and the cable reel. The radius change reduction gear incorporates an additional friction–pawl brake. The cable system includes a stationary pulley block, a running pulley block, and guy-ropes. The slewing gear is secured to the slewing frame's front part. Drive is transmitted from the motor through the coupling with a brake disk and via a toothed gear to the rim bearing.

The traversing gear is made up of four rail trucks with double wheels, secured to the undercarriage's cantilevers. Drive from the motors is transmitted via couplings with brake disks, a reduction gear box, and an open-toothed gear to the wheels.

Similarly to cranes with a trolley jib, tower cranes with a luffing boom have the following protection devices:

- Load limiter
- Pulley block top hoisting position tripper
- Rope unwinding trippers
- Traversing limiters

The crane's working motions are controlled from the operator's cabin.

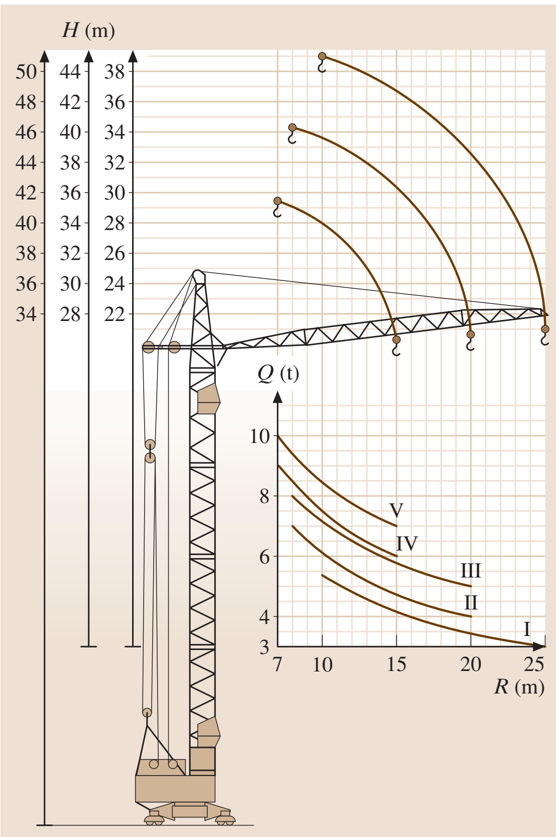


Fig. 14.107 Hoisting capacity as a function of radius and hoisting height for a 10 t-capacity crane with luffing boom

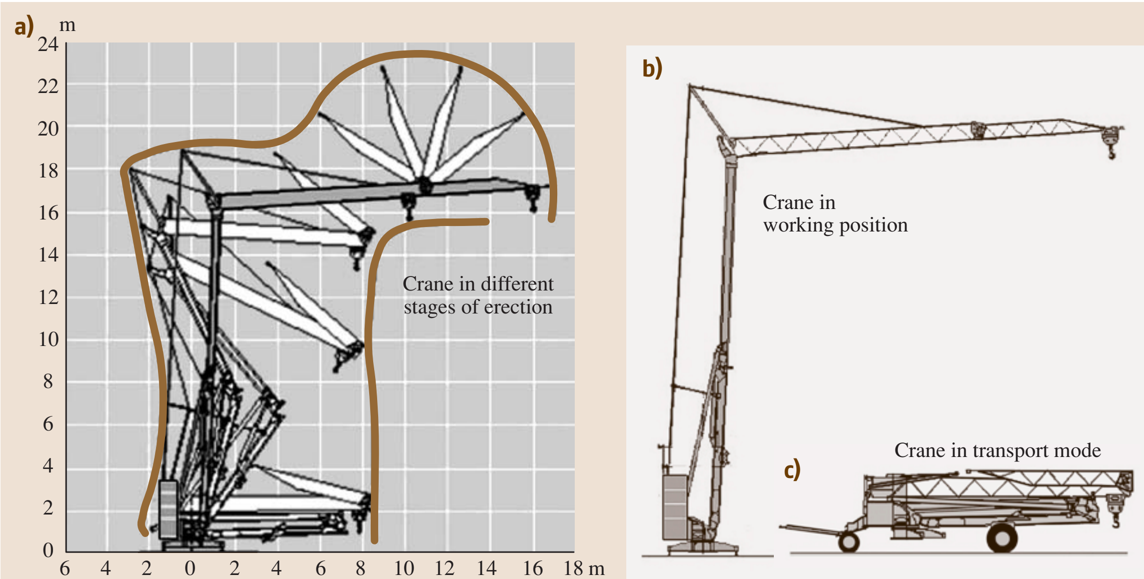


Fig. 14.108a–c Preparation of self-erecting crane for work: **(a)** crane in transport mode; **(b)** crane in different stages of erection; **(c)** crane in working position

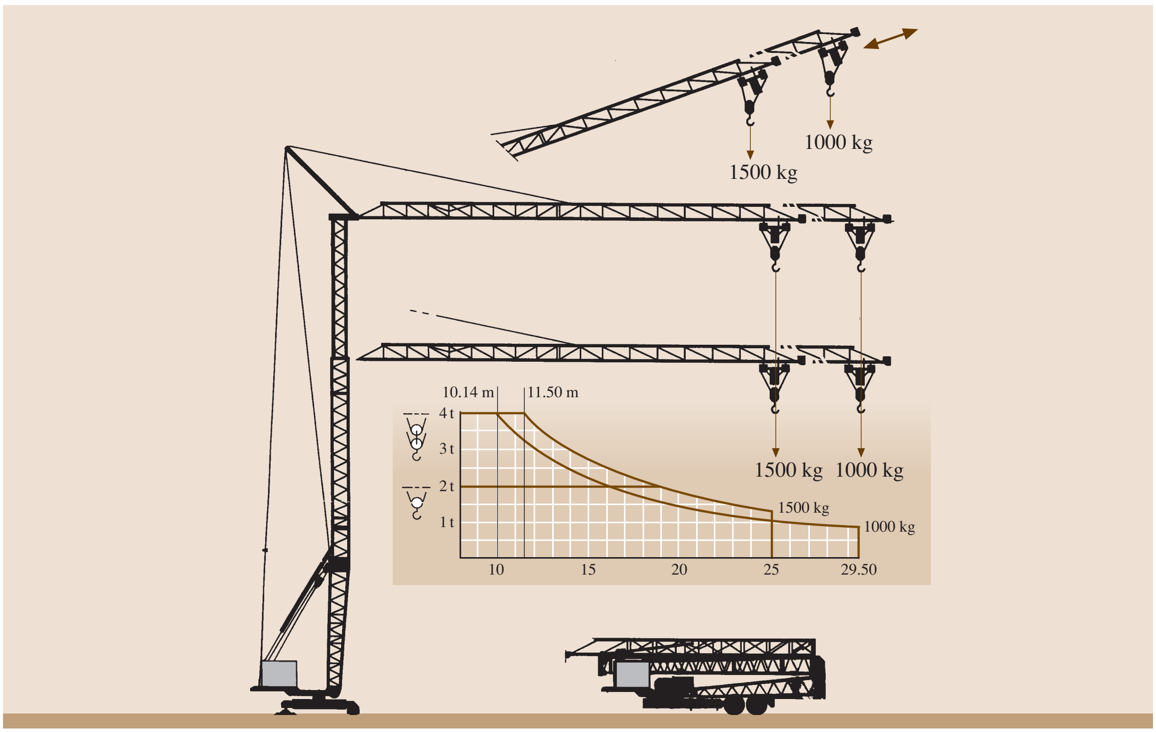


Fig. 14.109 Hoisting capacity versus radius for quick-assembling tower crane

A sample hoisting capacity–radius characteristic of a crane with a luffing boom is shown in Fig. 14.107.

Quick-Assembling (Self-Erecting) Cranes. Quick-assembling cranes form a separate class of tower cranes. Their characteristic feature is that they can be quickly assembled on a setup site. They do not require any other truck crane to be assembled, provided that the construction site has been properly prepared. The access road should be prepared such that the tractor towing the crane can reach the setup site and the latter should be practically at the same level as the access road. The setup site should be large enough for the vehicle with the ballasts to drive up close enough and for the crane to self-ballast (by means of its small auxiliary crane) and unfold. The crane is set up through the unfolding of the articulated mast and jib segments by its own drive units. During assembly the parts are connected by articulation but, once positioned, they are successively immobilized, forming a fixed load-bearing structure. The way in which self-assembling cranes are erected is illustrated in Fig. 14.108b, which shows four stages of assembly. Once the crane is properly set up, the jib's tip section is raised slightly. Then, using the crane's driving gears, its tower is put in a vertical position. Finally, the jib is completely unfolded.

Quick-erecting cranes are equipped with a trolley jib. They have a slewing tower which is secured to the base through a rim bearing.

An exemplary *hoisting capacity–radius* characteristic of a quick-erecting crane is shown in Fig. 14.109.

14.7 Equipment for Finishing Work

The aim of finishing work is to invest a structure with the design features and external and internal appearance. Finishing work includes:

- Roofing
- Outdoor (elevation) and indoor plastering
- Facing work
- Flooring
- Painting

The development of equipment for finishing work has been associated with the mechanization of the most labor-intensive and arduous activities. The first machines for finishing work were mortar pumps, followed by wood floor scrapers, parquet sanders, and mineral floor grinders. Later mechanical painting was introduced. Finishing work is carried out mainly on the construction site but efforts are made to move it to back-up facilities and transport ready-made elements to the site in order to increase work effectiveness. The range of finishing work is very wide in terms of both execution techniques and materials. The most commonly used equipment for finishing work is presented below.

14.7.1 Equipment for Roofwork

From the materials point of view the roofing used today can be divided into:

- Tar paper roofing mainly made from thermoweldable membrane
- Ceramic and stoneware tile roofing
- Bituminous shingle roofing
- Metal (zinc- and acrylic-coated steel sheet, rustproof sheet, zinc sheet, titanium–zinc sheet, copper sheet, and other) roofing
- Polyvinyl chloride (PVC) panel and ethylene propylene diene monomer (EPDM) membrane roofing

Most roofwork is done using hand tools. For making *thermoweldable membrane roofing* devices equipped with liquefied petroleum gas (LPG) burners are used. There are two methods of making insulating coatings from thermoweldable membrane:

1. By means of a roofing machine and
2. Using only a set of burners

A roofing machine consists of the following units: a tar paper spreader, a battery of burners, a flexible gas hose, and an LPG cylinder. The burners' flames melt the layer of pitch on the tar paper and at the same time heat up the base. Under these conditions the tar paper is pressed against the base by a roller made of segments to ensure that the tar paper is pressed down along the entire width of the roll. On contact with the base the pitch cools quickly, forming a layer that bonds the tar paper to the base.

The set of burners includes a six-burner battery as well as a double burner and a single burner. The six-burner battery is secured to a steel frame equipped with two wheels. The single burner and the double burner are

used to lay tar paper strips that are narrower than the roll and in not easily accessible places.

All burner models are offered with a *sustaining flame* option, improving work safety. In recent years special burners for lap welding have been introduced.

Ceramic tile or bituminous shingle roofing is laid by hand.

Metal sheet roofing is hand-made from prepared elements. For the preparation of metal sheet roofing elements hand tools (shears, bending machines), or in the case of large-sized roofing work power-driven tools, are used. In the latter case, metal sheet is guillotined to the appropriate dimensions and formed using bending-flanging machines (Fig. 14.110). Roofing elements properly prepared in the site yard are transported to the construction site and built in.

Sometimes roofing is preceded by the laying of insulation materials. Insulation materials 20–27 mm thick are secured to concrete or steel bases by means of special nails and plastic elements (flanged bushes) driven in using cartridge-charged fixing tools. Nails and cartridge-charged fixing tools can also be used to secure PVC, EPDM, bituminous, and profile metal sheet roofing to bases.

14.7.2 Equipment for Plaster Work

Plastering machines are used for preparing, feeding, and rendering all kinds of plaster on the walls and ceilings of erected structures.

All of these activities can be performed by one machine, the so-called plastering unit, or a set of individual machines, consisting of a mixer, a mortar pump, distribution hoses, and a spraying nozzle. Hence in the machinery used for plaster work one can identify the following groups of equipment:

- Equipment for transporting prefabricated dry mortar from a silo to a plastering unit
- Mortar and plaster mix mixers
- Mortar and plaster mix pumps
- Plastering units

Equipment for transporting dry mortar from a silo to a plastering unit (Figs. 14.111 and 14.112) can be used to transport dry mortars with a bulk density of 0.5–2.0 Mg/m^3. The maximum distance over which the material can be fed is usually 200 m and depends on the compressor's capacity, the material's properties, and the lie of the transport conduits. The equipment operates as follows (Fig. 14.111): when the plastering unit's reservoir fill-up signalling system signals that there is no mortar, the silo closing valve opens and the pressure vessel fills up. Once it is filled, the valve closes and the compressor starts blowing compressed air through the aeration fabric into the vessel. Liquefied mortar is pumped through a hose from the vessel to the plastering

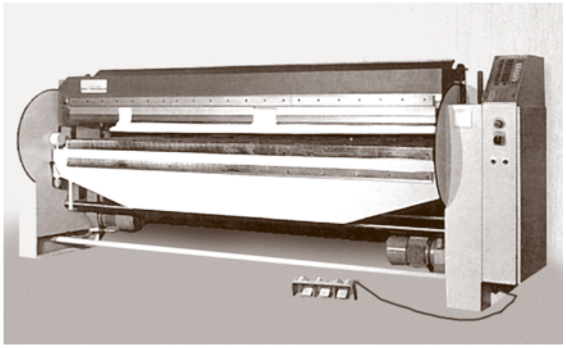


Fig. 14.110 Bending–flanging machine with roofing metal sheet profile programming

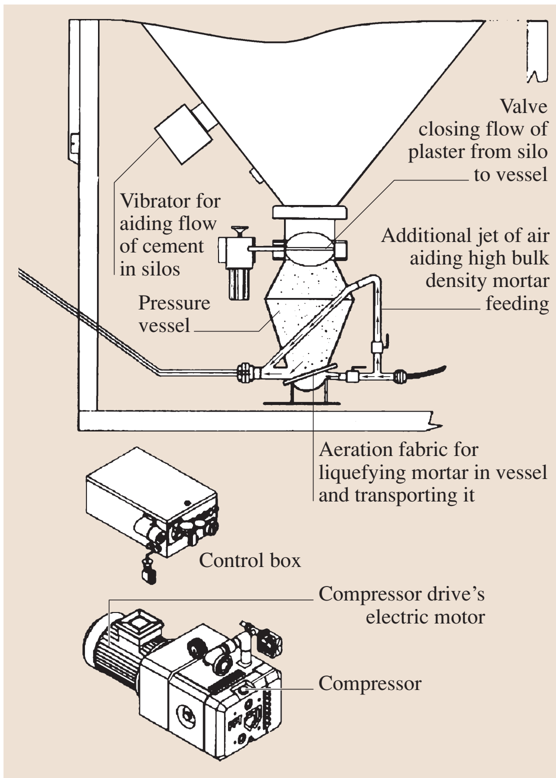


Fig. 14.111 Equipment for transporting dry mortar from silo to plastering unit

unit. If mortar with a high bulk density is to be pumped, the valve should be opened in order to aid the flow of mortar with an additional jet of air.

Portable equipment for transporting dry mortar, working in tandem with a plastering unit, is shown in Fig. 14.112. Besides a vibrator, an aeration unit is introduced in order to ensure proper flow of cement from the silo to the reservoir. The cement in the reservoir is liquefied by means of blow-in nozzles. The plastering unit's mortar reservoir is equipped with a lid with a fill-up signalling gauge and an air filter.

Dry mortar feeding systems can be made as mobile (equipped with a driving axle) or portable.

Mixers for Mortars and Plaster Mixes

Mixers for mortars and plaster mixes form a highly diverse class of plastering machines in terms of their size and principle of operation. The following kinds of machines are distinguished:

- Electrically driven, hand-operated mixers
- Continuous-type mixers
- Batch-type mixers

The machines are used for preparing masonry mortars, plasters, self-leveling mixtures, and so on.

Electrically driven, hand-operated mixers work by one or two electrically driven agitators that are manually introduced into a container to mix the contents.

Continuous-type mixers can be equipped with an open hopper (Fig. 14.113) or a dry mortar bin working with a dry mortar transport system (Fig. 14.112).

A diagram of a continuous-type mixer is shown in Fig. 14.113. In this mixer dry components are fed into the hopper and transferred by raking-out paddles and the feeding screw into the mixing unit, where water is added. The rate of flow of water into the mixer is controlled by a valve and a flowmeter.

Batch-type mixers perform the same function as continuous-type mixers, except that their operation is periodical and consists of the charging of components, their mixing, and discharging in succession. Their design is similar to that of concrete mixers. Pan-type mixers and paddle mixers are used. The most popular among the pan-type mixers are turbo mixers, planetary mixers, and turbo-planetary mixers. Among paddle mixers the most popular are mixers with a single helical agitator. Paddle mixers are discharged by tilting them or by opening a segment of the bottom.

It should be mentioned that also rotor mixers can be used to prepare gypsum mortars and mortars containing plastics. The components are mixed by setting them in rotary motion by means of a rotor.

Most mixers, both continuous and batch type, can work in tandem with mortar pumps.

Mortar pumps, when equipped with a mixer and a spraying gun, function as plastering units. The first mortar pumps were membrane pumps. Their maximum mortar pumping pressure was limited by the strength of

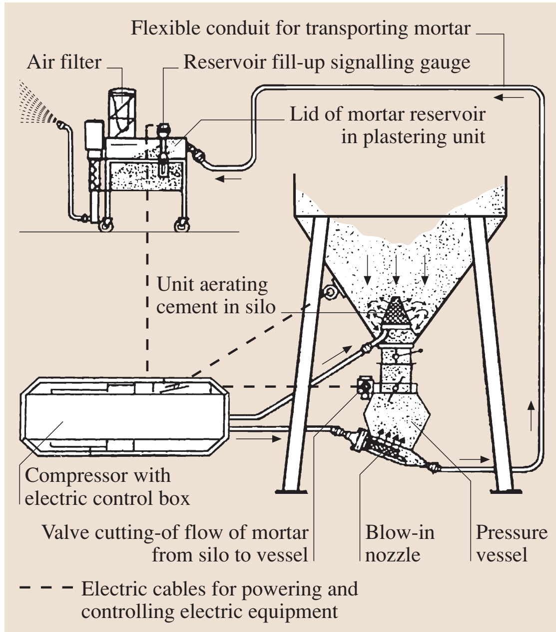


Fig. 14.112 Plastering unit working in tandem with equipment for transporting dry mortar

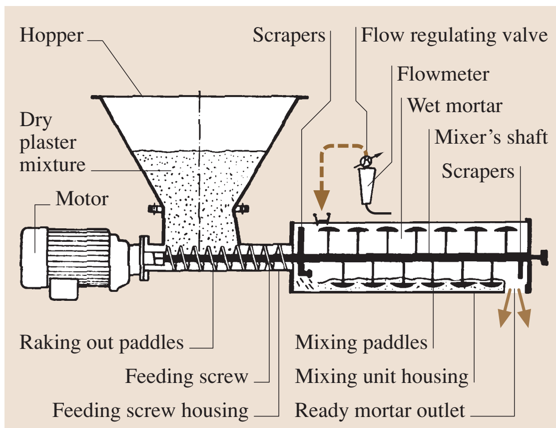


Fig. 14.113 Continuous-type mortar mixer with open hopper

the rubber membranes. As a result, the pump's lift was limited to about 20 m under average conditions. The desire to extend the reach of plastering and the required mortar forcing pressure has led to the development of piston pumps. The piston pumps currently produced by leading manufacturers can pump even heavy mortars to an elevation of 100 m at a forcing pressure of 6.0 MPa. The plaster feeding distances achieved depend on the forcing pressure, the mortar's composition, and the delivery rate. The delivery rate of piston pumps does not usually exceed 3.0 m^3/h.

A mortar pump design is shown in Fig. 14.114. The pump works such that, as the piston moves to the right, mortar is sucked through the suction valve into the working chamber. As the piston moves to the left the pressure of the mortar closes the suction valve and opens pressure valve. As the piston moves again to the right, mortar is sucked in again while the mortar on the piston's right side is forced into a pipeline. The pump makes it possible to minimize pressure fluctuations and therefore to maintain constant mortar spraying parameters and increase the fatigue strength of the mortar pipeline's flexible hoses. The travel of the pistons occurs as a result of the rotation of the cam pushing the roller during, respectively, the delivery stroke and the suction stroke.

The operation of a popular two-piston mortar pump with a cam drive is illustrated in Fig. 14.115. The function of the compensating piston is to equalize the mortar forcing pressure during the suction stroke of working piston. The suction stroke of the working piston is aided by a spring and the return stroke of the compensating piston results from the mortar pressure.

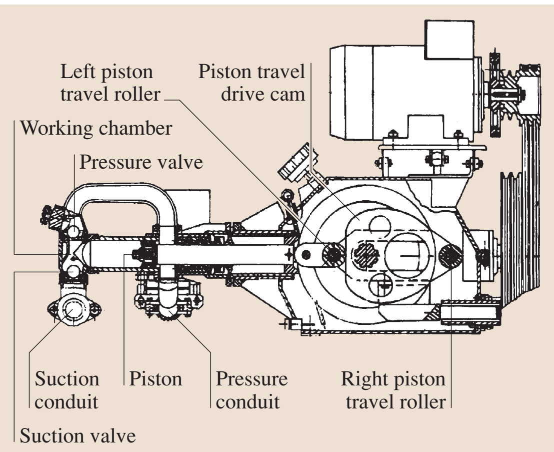


Fig. 14.114 Mortar pump with bilateral action piston

Besides piston pumps, screw pumps form another class of pumps. They are used for applying thin finishing coats of gypsum mortars, lime–gypsum mortars, and mortars with plastics. In recent years they have also been used for conventional mortars, competing with piston pumps. The principle of operation of the screw pump (Fig. 14.116) is to force mortar in the closed spaces between the helical surfaces of the rotor and sta-

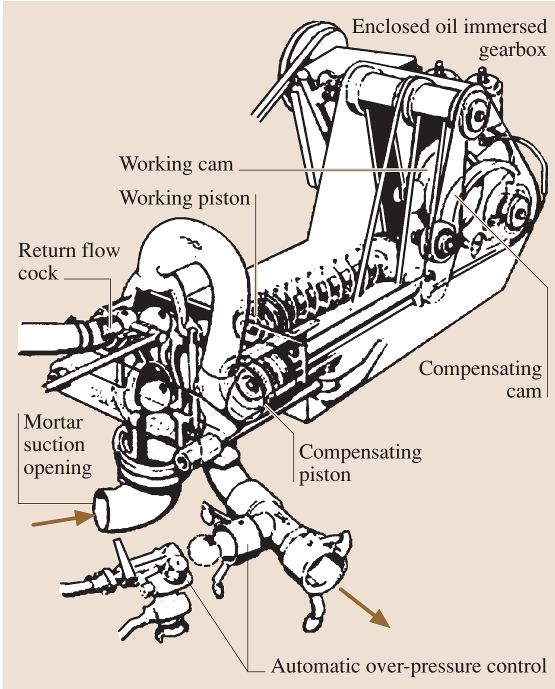


Fig. 14.115 Diagram of two-piston mortar pump with mechanical cam drive for the pistons

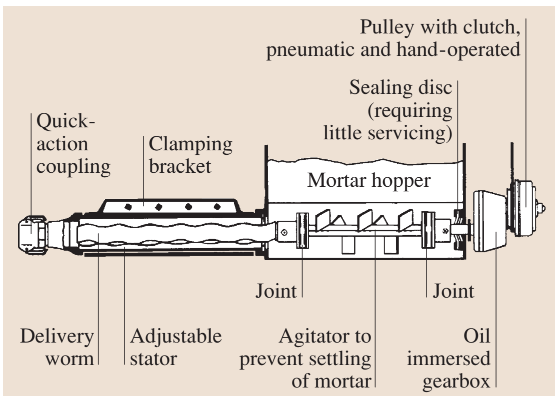


Fig. 14.116 Worm pump with adjustable stator

tor. The pump's stator is made of rubber that is resistant to compression and chemically aggressive liquids. The screw pump's efficiency decreases with operating time as a result of abrasive wear of the rotor and the stator. As the delivery of the pump decreases so does the forcing pressure. For the pump shown in Fig. 14.116 a decrease in pump delivery is counteracted by compensating the clearance between the rotor and the stator by means of a clamping bracket. Mortar is fed into the screw pump usually from the mortar hopper equipped with an agitator, which prevents the settlement of solid particles and the segregation of the material.

Plastering units are machines that mechanize the preparation and rendering of mortar. In the case of conventional cement–lime mortars, a plastering unit performs the functions:

- Charging of mortar components
- Mixing
- Straining
- Transport to rendering site
- Rendering on walls and ceilings

The introduction of plaster-like mixes and putties limited the activities connected with the preparation of mortar to only its transport or to mixing a dry mixture with water.

Depending on the plasters being made, plastering units can be divided into three classes that differ in their structural aspects:

- Plastering units for traditional lime and cement–lime mortars
- Plastering units for gypsum mortar
- Plastering units for plaster-like coats (PVC mortars)

A plastering unit for making traditional plasters from lime, cement–lime, and cement mortars is shown in Fig. 14.117.

In some plastering units, similarly to in concrete mixers, charging buckets are used in order to facilitate the loading of the components into the mixers. Plastering units are equipped with a remote control system for controlling the operation of the pump. If the spraying gun's air valve is closed, the pump's drive is automatically switched off and mortar feeding stops. The opening of the air valve results in the switching on of the pump's drive. As dry plaster mixes have become increasingly popular, plastering units for traditional mortars increasingly often feature screw pumps besides piston pumps.

A plastering unit for feeding and rendering mortars from ready-made dry plaster mixes is shown in Fig. 14.118. After refitting the pump and changing the mortar feeding hose, the plastering unit can also be used for self-leveling floor compounds.

A characteristic feature of the plastering unit shown in Fig. 14.118 is the reduced size of the mixer, whose function is performed by a mixing chamber with an agitator in the form of helical segments.

The rate of delivery of plastering units for traditional mortars is usually up to 3 m^3/h.

For feeding traditional plaster mortars, hoses that are 52–58 mm in diameter with tip elements 32–36 mm in diameter are usually used. For feeding and spraying special media, pressure hoses with increased strength are used.

Plastering units for traditional mortars can be adapted for spraying mixes to protect steel structures against fire, self-leveling mixtures, and similar materials.

Plastering units for gypsum mortars perform the functions of feeding, mixing, pumping, and pneumatic spraying of mortar onto a surface to be plastered. Their design is very similar to that of plastering units for dry plaster mixes. The structure of a plastering unit for gypsum mortars is shown in Fig. 14.119.

The mortar mixing chamber can operate in two positions: vertical and inclined. A vertical mixing chamber position is used for spraying ready-made gypsum plaster mixes. If the mixing chamber is inclined, a stroke pump can be used. For mounting and dismounting of the pump the mixing chamber is placed in a horizontal position.

A characteristic feature of plastering units for gypsum mortars is the common drive for the agitator and the pump, located in series.

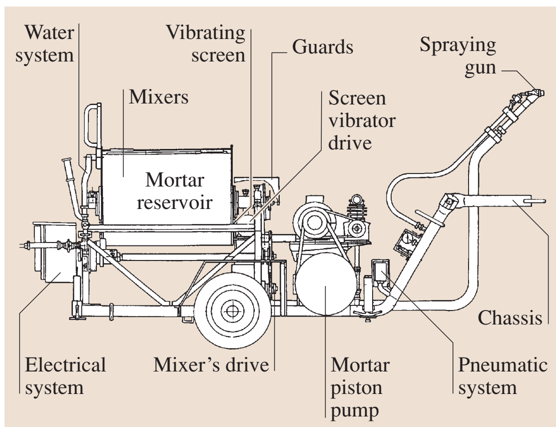


Fig. 14.117 Plastering unit for conventional plasters

In modern plastering units mainly screw pumps are used because of the following advantages:

- Pressure stability (practically no pressure fluctuations)
- Rate of flow can be adjusted by:
  - Changing the speed of rotation of the screw pump's rotor by controlling the speed of the driving motor
  - Adjusting the clamping pressure of the metal mantle on the stator (if the pump has such an option)

The rate of delivery can also be changed by replacing the pump with a unit with the desired flow rate.

Another useful feature of the screw pump is the possibility of changing the direction of flow by reverse pump rotation in the case of blockage of the pressure hose.

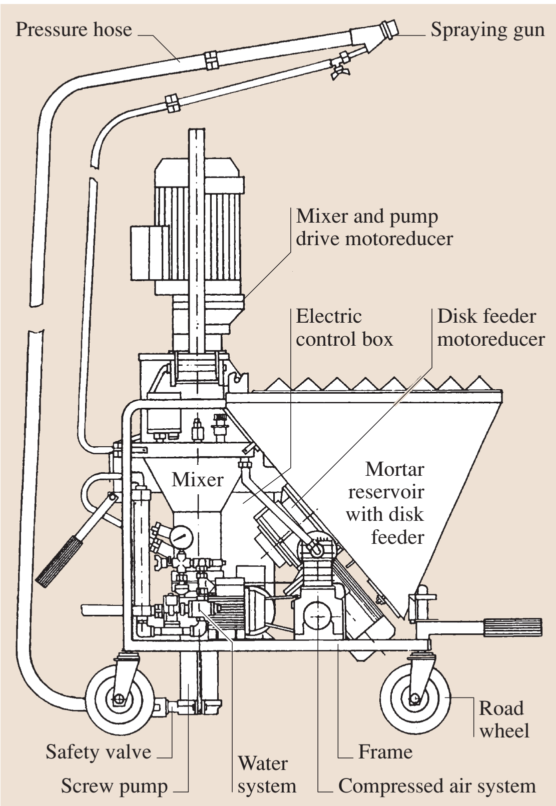


Fig. 14.118 Plastering unit for preparing and rendering mortars made from ready-made dry plaster mixes

The gypsum mortar flowing out of the spraying gun is torn apart by an axially introduced jet of compressed air and ejected from the nozzle at an accelerated speed. This ensures better adhesion of the rendered layer to the base. The shape of the jet can be modeled by adjusting the depth of insertion the compressed air nozzle into the spraying gun and by attaching spray-gun tips with different outlet diameters. Hoses with an inside diameter of 25 mm (sometimes 19 and 32–36 mm) are usually used for feeding gypsum mortars.

Electric motors with a power of about 5 kW are used to drive plastering units for gypsum mortars. They make it possible to feed mortar for a distance of 20–40 m at a working pressure of up to 4.0 MPa.

Plastering units for plaster-like coats (mortars containing plastics) are compact devices weighing a few tens of kilograms. They mix, pump, and render thin plaster coating mortars, adhesives, paints with fillers, dense insulating fluids, gypsum mortars, and so on.

The structure of a plastering unit for plaster-like coats is shown in Fig. 14.120. The reservoir can be charged with dry mortar, adding water subsequently, or with a mortar–water mixture. In order to ensure easy access for the spraying gun (particularly in window

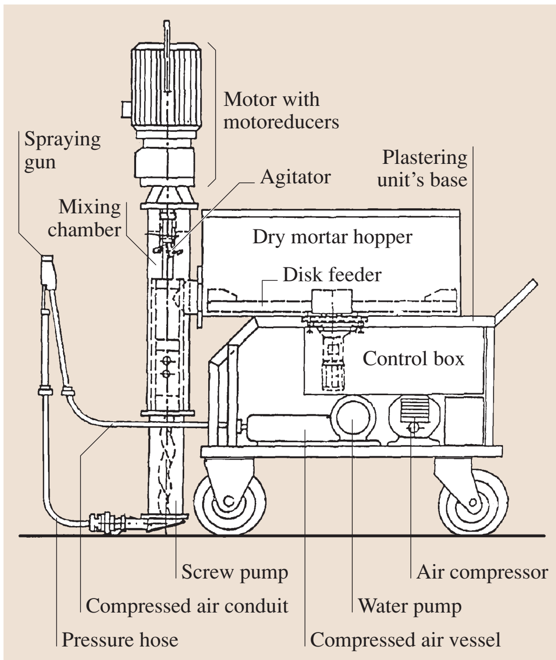


Fig. 14.119 Plastering unit for gypsum mortars

and door openings) screw pumps with a delivery of 0.3–0.7 m^3/h are used.

Hoses that are 25 mm (occasionally 19 mm) in diameter are used for feeding plaster mix. The simplest plastering units of this type can work in tandem with an external general-use air compressor. Plastering units are offered with an electric or diesel drive.

For operational safety reasons pressure conduits in all kinds of plastering units are protected by safety devices against an excessive increase in mortar or plaster mix pressure. Currently in most plastering units electromagnetic protection in the form of *pressure cut-offs* are used. Plastering units for conventional mortars, equipped with a piston pump, usually have double protection systems.

14.7.3 Equipment for Facing Work

Facing work consists of finishing surfaces by fixing decorative layers of different materials to them. The range of facing work is very wide. The most commonly used facing materials are: ceramic tiles, stoneware, and natural and artificial stone tiles.

The basic machine for facing work is a cutting-off machine. Such machines can be used not only for cutting the aforementioned materials, but also to cut concrete blocks, reinforced concrete, bricks, roof tiles, and so on [14.39].

Four types of cutting-off machines can be identified (Fig. 14.121):

- Type 1: A machine with a movable table having a fixed (permanently or by means of clamps) or swinging moveable cutting head (tiltable or not), which is located over the table
- Type 2: A machine with a fixed table having a horizontal moving cutting head and, if applicable, vertically adjustable and tiltable cutting head located over the table
- Type 3: A machine with a fixed table having a vertically moving cutting head
- Type 4: A machine with a fixed or movable and/or inclinable table having a fixed cutting head, intended for use only with continuous-rim tools having a maximum diameter of 250 mm (the motor being located under the table)

Cutting-off machines are used for cutting along straight lines, in planes inclined at various angles. The working tool is usually a solid or segmental disk with a diamond glued to it along its circumference, forming a ring. The disk is cooled with water. For less precise cutting (e.g., of bricks) disks with a diamond and metal can be used. The cutting disk is usually driven directly by a motor or sometimes via a belt transmission.

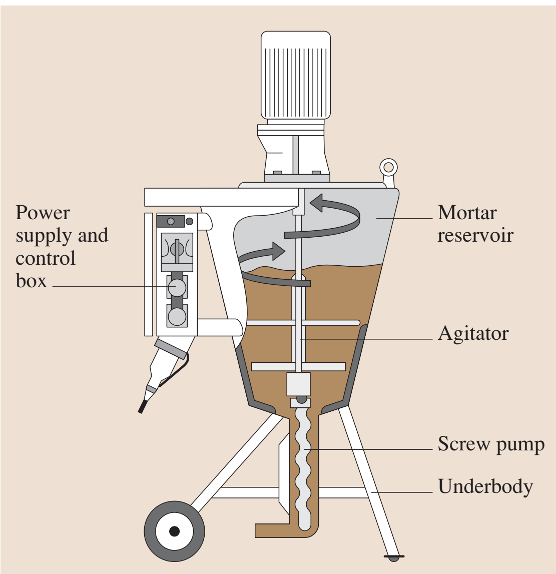


Fig. 14.120 Plastering unit for mortars containing plastics

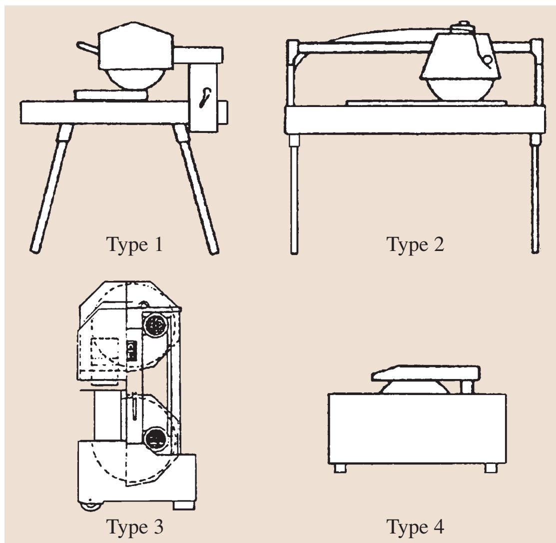


Fig. 14.121 Sketches of different types of cutting-off machines

The cutting disk is cooled and the plate of material being cut is wetted by immersing part of the disk in a tank with water, or by feeding water, flowing down gravitationally from a tank located over the disk or forced by a water pump, to the cutting disk. Wet cutting prolongs the life of the disk and eliminates dust emission.

The structure of a cutting-off machine is shown in Fig. 14.122.

The power of driving motors in cutting-off machines ranges from 200 W to 3 kW.

The group of machines used for facing work also includes a mixer for preparing adhesives and mortars. A mixer for preparing 40 l of mortar by mixing dry components with water is shown in Fig. 14.123. In order to fill bin one should tilt, by means of the handle, the mixing unit into the upper position and lock it with bolt. The handle is used to relocate the mixer.

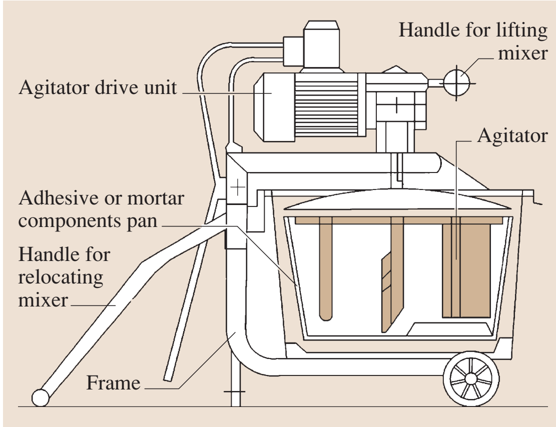


Fig. 14.123 Mixers for adhesives and mortars used in facing work

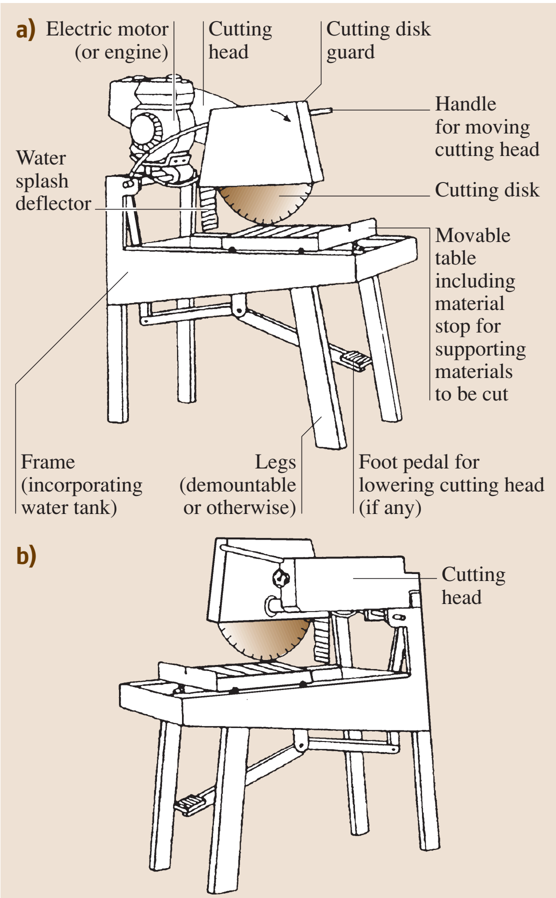


Fig. 14.122a,b Examples of cutting-off machines: **(a)** cutting-off machine with internal combustion engine; **(b)** cutting-off machine with electric motor;

14.7.4 Floor Work

Floors are elements of buildings consisting of several layers and made almost entirely on the construction site.

Depending on the floor materials, different machines and equipment are used. The machines most frequently used for floor work are:

- Pneumatic feeders for dense mortars (feeder of fresh concrete mix and mortar)
- Vibrating beams (described in Sect. 14.3)
- Floating machines for concrete (described in Sect. 14.3.8)
- Grinders for stone and mineral floors
- Sanding–polishing machines for wooden floors (parquets)

A pneumatic feeder for dense mortars is used for mixing the components of cement mortar and delivering the latter to the placement site. A scheme of such a feeder is shown in Fig. 14.124. The vessel filled with the appropriate amount of water can be charged with mortar dry components manually or by means of a charging bucket. Compressed air supplied to the vessel and dosing unit forces mortar out of the vessel, but in the dosing unit the stream of mortar is separated by compressed air. As a result, in the pressure hose it already has the form of a series of small portions separated by spaces filled with compressed air. This transport system ensures stable flow of mortar into the hose's tip placed on

a tripod. Depending on their size, machines operating on this principle have a mortar capacity of 2–6 m^3/h and can feed mortar to an elevation of 50 m.

Electric motors or self-ignition combustion engines with power of up to 30 kW are used for driving pneumatic feeders for dense mortars. The most common pressure hose diameters are 63 and 68 mm.

Grinders for stone and mineral materials are being increasingly less frequently for finishing work in construction because of a change in the materials used. Commonly used until recently, terrazzo – which required grinding – has been replaced by lining in the form of stone and ceramic tiles with a ready-made smooth surface not requiring any machining after laying.

Wood floor sanders and sander–polishers form a numerous group of machines and find application in the construction of new structures and in renovation. The following types of machines can be identified:

- Drum (single- and double-drum) sanders
- Disk sanders
- Oscillating sanders

Drum sanders are intended for rough and finishing sanding of wooden floors. Sanders with one and two working drums can be distinguished. In the latter case, one drum performs sanding while the other stretches the abrasive belt. Both drums have a horizontal axis of rotation. The sander's working element is an abrasive (sandpaper or abrasive cloth). The sanding drum's working width is up to 250 mm and is limited by the necessity for the drum to exert appropriate linear pressures (about 20 N/cm) on the surface. The design of a single-drum sander is shown in Fig. 14.125.

A drum sander may weigh as much as 90 kg and the power of the driving motor can reach 3.5 kW at a drum rotational speed of about 2300 rpm.

Electric motors are exclusively used to drive sanders because the latter are intended mainly for work indoors and the possibility of ignition of the wood dust collected in dust bags has to be eliminated.

The described drum sander cannot sand the floor under heaters. For this purpose *disk sanders* (Fig. 14.126) are used. The working tool in this machine is an abrasive disk mounted at an angle of about 3° relative to the base. Sandpaper is Velcro-fastened to the disk or clamped with a nut. Because of the disk's inclination, its working base–contact surface amounts to about a third of the disk's surface area.

Power is transmitted to the disk by a V-belt or a cogbelt. The driving motor's power does not exceed

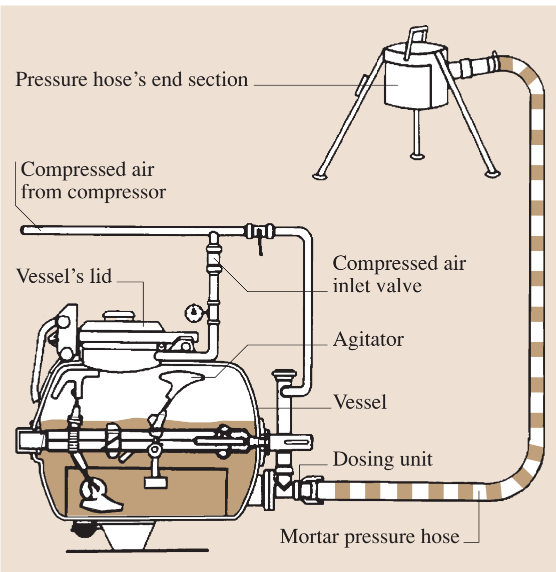


Fig. 14.124 Scheme of pneumatic feeder for dense mortars

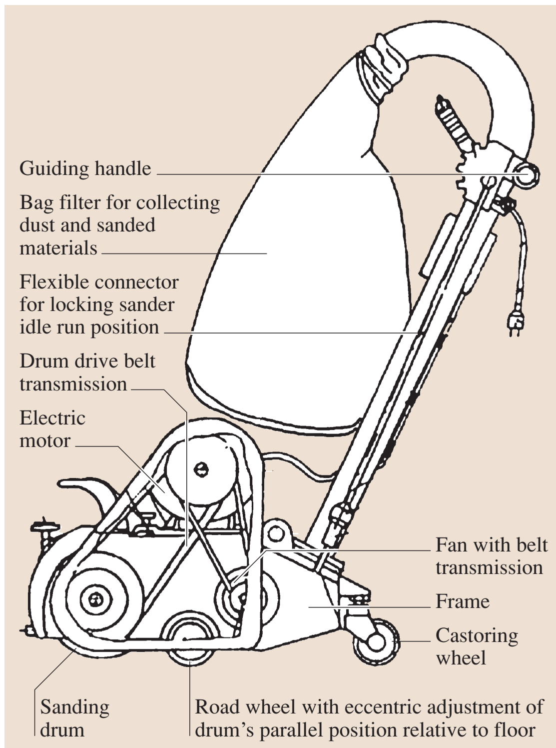


Fig. 14.125 Single-drum sander for parquet floors

2.0 kW at a rotational speed of about 4300 rpm. In currently manufactured disk sanders, disks about 180 mm in diameter are used.

In some sander designs, lights are fixed to the sander's body to illuminate the sanded surface at a small angle. This makes it easier for the operator to notice any surface irregularities and to obtain the required quality of sanded surface.

To sand corners of rooms and places not easily accessible to drum sanders and disk sanders *oscillating sanders and belt sanders* are used. These are typical mechanized devices with an electric drive.

Besides the above basic machines for floor work many small mechanical devices are used [14.40]. Their selection depends on the floor materials. This group includes:

- Industrial vacuum cleaners, thermal and mechanical cutters for polystyrene foam, sweepers, floorwashers, floor polish spreaders, and floor polishers
- For wooden parquet floors: hand-guided circular saws, circular saws with a table, and circular saw–fretsaw machines
- For laying plastic flooring: welding cord groove millers, circular tools, and welders

14.7.5 Equipment for Painting Work

Paint coatings are a very common way of finishing both building interiors and elevations. Paint coatings are applied to the surfaces of walls, ceilings, window and door openings, pipes, and heaters. Commonly used materials are emulsion, synthetic, and oil paints. The use of water (limewash and size color) paints is on the decline. In small rooms, paint work is as a rule done by hand. Painting units are used to apply paint coats in large rooms.

Depending on the compressed air or paint pressure, painting units can be divided into three groups:

- Low-pressure (up to 0.55 MPa) painting units
- Medium-pressure (up to 2.5 MPa) painting units
- High-pressure (up to 25 MPa) painting units

Besides the above, electrostatic painting units are also distinguished.

Low-pressure painting units usually consist of a spraying gun, a paint reservoir, and an air compressor.

Spraying guns equipped with a paint reservoir are general-use devices. Paint reservoirs can be attached to a spraying gun from the top or bottom. There are also designs in which a jet of compressed air from a compressor is used to spray paint. The spraying parameters are set by means of valves, which control the paint and compressed air flows.

In medium-pressure painting units, similarly to in high-pressure painting units, paint is pumped without the action of air and so they are often called *airless*. Currently they are superseded by high-pressure painting units.

High-pressure painting units are used in construction for painting large surfaces and on roads to paint railings and roadway signs. The basic working unit is a piston pump which ensures a pressure as high as 25 MPa in the pressure hoses. The pumps and the paint forcing system's components are made of abrasion-resistent materials (tungsten carbide). High-pressure hoses, 12–16 mm in diameter, are usually employed. The hoses are protected against electric charge accumulation – typically by a conductor connected to earth.

Spraying gun nozzles ensure the rapid discharge of atomized paint in the form of a jet whose shape depends on the nozzle's shape (e.g., conical or flat triangular). The kind of nozzle and the spraying pressure are selected to suit the kind of work, e.g., the painting of large surfaces or the precision painting of stripes. The operation of modern high-pressure units is simplified as far as possible.

High-pressure painting units can be used for applying water-based paints, solvent paints, latex coats, acrylic coats, and so on. These machines are powered

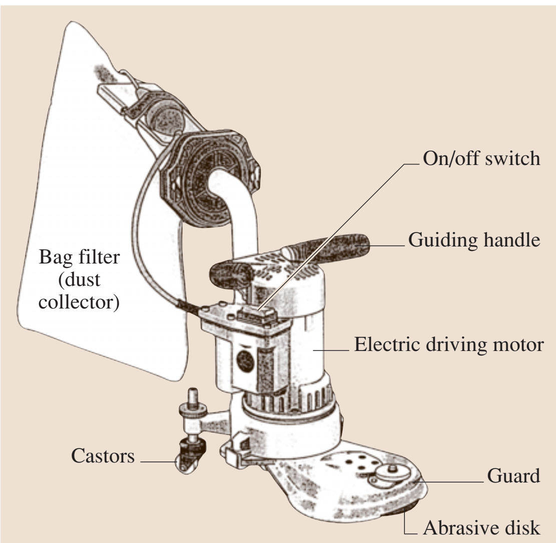


Fig. 14.126 Disk sander for parquet floors

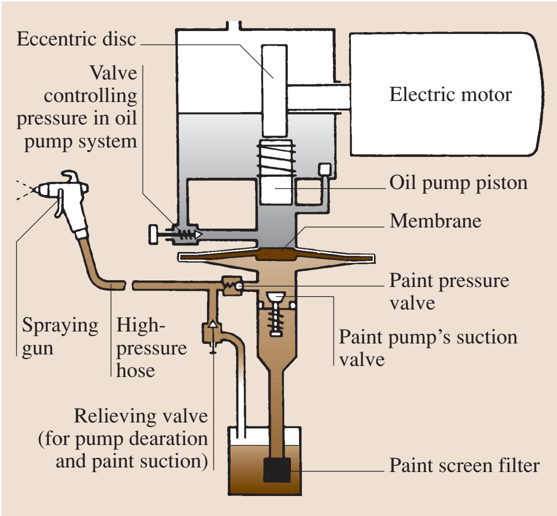


Fig. 14.127 Scheme illustrating the operation of a high-pressure (airless) painting unit

by electric motors, pneumatic engines or combustion engines, with a power as high as 4.1 kW.

A high-pressure painting unit is shown schematically in Fig. 14.127. The piston causes the pulsation of a membrane and the suction of paint from the reservoir through a filter and its forcing into the hose and spraying gun. A valve in the oil pump system is used to set the spraying pressure.

A typical high-pressure (airless) painting unit design is shown in Fig. 14.128. Paint is sucked in from a reservoir by the paint pump and forced (at a maximum pressure of 17.5 MPa) into the spraying gun with a nozzle 0.43 mm in diameter. The rate of painting is about 4 m^2/min.

It should be noted that in paint work, besides the application of paint coatings, preparation of surfaces and paints plays a vital role. Industrial vacuum cleaners, sliding grinders, and corner grinders are used for preparing the base [14.40].

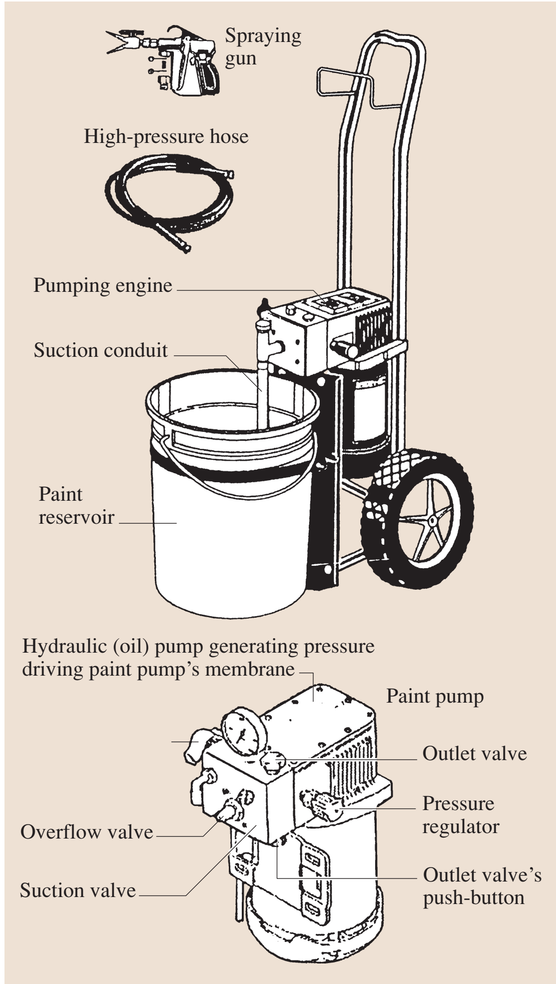


Fig. 14.128 High-pressure (airless) painting unit

Paints are mixed by means of hand-operated and mechanical mixers and strained using screens to remove impurities.

14.8 Automation and Robotics in Construction

Even today many people employed in construction associate the use of robots with the manufacturing industry, mainly the automotive industry, where they are typically employed to spray paint and spot weld the car body. However, considerable advances have been made in robotics applications in construction.

Robots are used not only because of their technical–economic advantages; they also result in improved work quality, increased output, reduced task realization time, reduced labor costs, and improved operational safety. The latter applies especially to work in conditions that are hazardous and detrimental to health, such as sewer

inspection, demolition work, underwater work, work in radioactive environments, earthwork on slopes, and work at heights. In many cases, it is for safety reasons that robots must be employed. A survey has shown that about 300 devices are currently available in the robot and automated equipment market.

The rapid development of robotics for construction applications in Japan began in earnest in the 1980s. Its direct cause was the shortage of labor in construction. Japan's business community turned to the government for permission to import workers from abroad. Because of the government's refusal, construction companies were forced to invest in research and development of robotics for automation in the execution of construction work. Another motivation was the difficulty with conventional performance of tasks that were deemed hazardous or arduous for human workers to perform. Waseda University's Systems Science Institute in Tokyo pioneered Japanese concepts of implementing industrial robotics on construction sites. Leading engineering construction firms such as Shimizu, Obayashi, Kajima, Taisei, Fujita, and others produced their own construction robot prototypes for various applications on construction job sites. These applications included single-purpose construction robotics as well as entire robotic systems for the performance of high-rise building construction.

In the USA the Robotics and Field Sensing Committee of the American Society of Civil Engineers engaged in coordinating research in automation and robotics for construction. The centers of active in this field included Carnegie Mellon University (Pittsburgh, PA), the University of Texas at Austin, Purdue University (West Lafayette, IN), the University of Southern California (Los Angeles), and North Carolina State University (Raleigh). Carnegie Mellon was a US pioneer in these developments, having started independent research and development of construction robotics in the early 1980s, shortly after the early developments of construction robotic concepts in Japan.

Also in the 1980s, construction automation and robotics concepts were researched in the former Soviet Union. These included systems and hardware developments at the Moscow Civil Engineering Institute and at the Central Laboratory for Construction and Heavy Manipulators [14.41–44]. Subsequent or parallel developments took place in France (*Centre Scientifique et Technique du Batiment*), Germany (the Fraunhofer Institute for Production Automation, Technical University of Karlsruhe, and the Technical University of Munich), the United Kingdom (Lancaster University, City University in London, and the former Bristol Polytechnic), and Spain (the Carlos III University in Leganés, Madrid).

As a result of the development of automation and robotics in construction in the last three decades this domain, integrating the achievements of robot technology, information technologies (IT), and design for construction (DfC), has acquired the status of a scientific discipline. Twenty years ago the International Association for Automation and Robotics in Construction (IAARC) was formed. This association organizes annual International Symposia on Automation and Robotics in Construction (ISARC). The 21st ISARC was held in Jeju (South Korea) in September 2004, and the 22nd ISARC took place in Ferrara, Italy in September 2005. Papers published in the symposium proceedings represent the latest achievements in this field.

In automated construction equipment two kinds of devices can be distinguished: teleoperation manipulators, referred to as construction manipulators, and construction robots. Construction manipulators are remote-controlled by the operator while construction robots are autonomous computer-controlled devices. The robot's software allows it to perform variable tasks within its application range.

In the development of automated equipment, four stages corresponding to the particular generations of this equipment can be distinguished [14.45].

The first generation, which can be called *automated construction devices*, was developed by outfitting existing construction equipment with electronic sensors and digital control. The principles underlying the development of the first-generation robots are still used in the automation of many types of construction machines. Expensive construction machines are equipped with sensors and computer control. The latter includes a data-processing unit and feedback control. Such adaptations are used in excavators, cranes, pile-driving equipment, transport to the horizontal transport of output, and in concrete mix transport and placement.

The second generation is associated with the application of manipulators to such construction works as laying reinforcement, building walls out of building blocks, floating concrete surfaces, and laying tiles. Manipulators are newly designed devices but still controlled by operators.

The third generation includes autonomous robots with no operator involved in their control. They need an operator only to prepare them for work and sporadically during work. They find application in many kinds

of construction work such as trenching, masonry work on construction sites, and in precast concrete plants for wall elements production, the assembly of steel structures, the transport of materials to the place where they are to be built in, the spraying of fireproofing insulation onto steel structures, and painting. Moreover, they are used for testing building structures and elements, e.g., sewers, the adhesion of tiles to tall buildings' elevations, and testing the quality of welded joints in steel structures.

Fourth-generation robots are designed for specific structures, taking into account the materials to be used. They are employed in automated building construction systems (ABCS). These robots are designed to be an integral part of a new construction methods which are adapted to the use of construction robots, known as design for robotic construction (DfRC).

All four generations of automated construction equipment are used in construction, and transition from one to another has been evolutionary. A major feature of this process is that the role of the operator is reduced, or completely replaced, by computer control.

Automated construction equipment used for particular kinds of construction work is described below.

14.8.1 Automation of Earthwork

Because of its significant share in the total building production, automation of earthworks deserves special attention [14.46]. However, some factors in earthwork make its robotization difficult, including:

- Variable forces of the ground-working tool interaction, due to the variability of the physical parameters of soil and material nonhomogeneity
- Variable height of the terrain
- Occurrence of buried objects such as electric cables, pipelines, etc.
- The possibility that machines working close to the edge of excavation edges may overturn
- The potential hazard to workers who find themselves within the machine's range of operation

For these reasons, remote-controlled machines and machines with a robot control system effecting the working tool motions controlled by computer-driven programs are usually employed in earthwork automation instead of true robots.

Such machines are used in work environments with radioactive and chemical contamination, in pile driving, underground work, tunneling, deep point-excavation, diaphragm excavation, and pneumatic caisson work.

The automation of earthmoving machines is proceeding in three directions:

- Use of remote control in machines
- Adaptation of machine control systems for automated execution of specific kinds of work
- Development of autonomous robots

The first direction (remote control of earthmoving machines) is the most common commercially available solution. On the basis of a three-dimensional image the operator controls the operation of machines and the loading of the excavated material. Remote control can be combined with a semirobotic control system when quality workmanship is required.

The second direction (adaptation of the machine's control system to make its fittings perform a specific task) includes, for example, the steering of the excavator bucket so that it moves along a predetermined trajectory [14.47–50], the control of the dozer blade to ensure that a smooth, leveled surface is obtained, and the control of drilling attachment mounted on an excavator diaphragm wall excavation.

The third direction is the development of autonomous third-generation robots for earthwork. The robot's design should be adapted to adverse service conditions and hazards.

Example Applications

The research and development work on the automation of earthmoving machinery is primarily concentrated on single-bucket excavators and then dozers and loaders. Many manufacturers offer machines operated by remote control. Extensive research aimed at developing robotic components and adapting the robots to practical service conditions is being conducted by various corporate laboratories throughout the world, including, e.g., the research and development units of the Caterpillar Corporation and Komatsu.

This research covers modeling of excavators as robotic manipulators [14.51], cognitive force control of excavators [14.52], soil mechanics with regard to ground-working tool interaction, kinematic and dynamic analysis of mechanisms, sensors enabling the determination of the position of mechanisms in a chosen location and in an absolute reference system, bucket trajectory optimization (leading to improved output and fuel economy) [14.47–50], and sensors detecting the presence of people within the machine's work range

and making it possible to determine the positions of the excavation's edge and the output removal vehicles.

An example of a remote-controlled machine is the pull shovel shown in Fig. 14.129. It is radio-controlled and has an operating range (distance from the control panel) of 1500 m. The working system's cylinders and travel drive are controlled by levers on the control console. Two video cameras, mounted outside the excavator, transmit a picture of the working area. A third camera inside the operator's cabin shows the indications of the gauges.

Fig. 14.129 Remote-controlled pull shovel

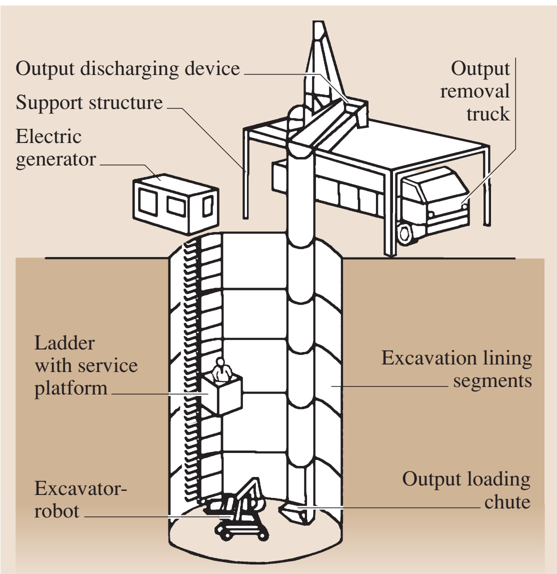


Fig. 14.130 Excavator with associated equipment for making deep point-excavations

Another example of a remote-controlled excavator is the excavator shown in Fig. 14.130 [14.53]. The machine is intended for making deep excavations, vertical transport of output, and loading it into transport means. A slewing body with excavating tools and containers or negative-pressure conduits for transporting output are mounted on the crawler chassis. The excavation's minimum diameter is 3 m.

The excavation rate and the output loading rate can be adjusted to the ground's properties. If soft rock is encountered, a milling drum can be mounted.

The excavator is used in mountainous terrain not easily accessible to pile-drivers to avoid the hazards (landslides, subsoil waters, toxic gases, and falling objects) to which the operator would otherwise be exposed.

Among point excavators there is a machine designed for work in hard rock [14.53]. Its rotary tool, mounted on a 0.7 m^3 undercarriage, is hydraulically driven. Boreholes 846 mm in diameter can be drilled.

Besides whole machines, computerized systems for controlling construction machines, allowing one to automate partially the operation of machines, are also available. Offered control systems can be installed on excavators, dozers, graders, and asphalt pavers. They incorporate tachometers, global position system (GPS) receivers or laser surveyor's levels. A simple example here is a control system for setting the position of the dozer's blade (Fig. 14.131) so that smooth, leveled soil surfaces can be obtained. A rotary laser on a tripod produces a horizontal reference plane. The control system with a signal receiver, mounted on the dozer, automat-

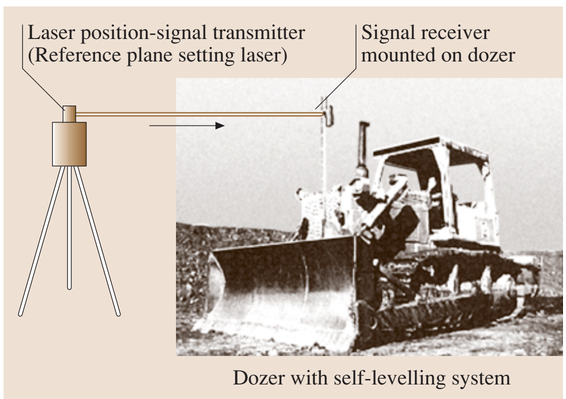


Fig. 14.131 Dozer with blade position controlling system for precision leveling of terrain

ically adjusts the elevation of the blade as the laser receiver follows the adopted reference plane.

A computerized control system for a grader works as follows. The task to be performed is stored in the memory of the machine's PC in accordance with a digital work execution scheme. The machine's actual location relative to the design data is determined by a tachometer or the GPS, which compares it with the design terrain elevation at a given point and on this basis sends signals to the machine's hydraulic system. For one such control systems, the accuracy of leveling is $\pm 5-10$ mm when a tachometer is employed and $\pm 15-20$ mm when a GPS system is used. Thanks to automatic control the number of passes of the machine, and so the work realization time and cost, can be reduced.

Besides control systems for single machines systems for the remote control of a set of earthmoving machines (Fig. 14.132) working in areas posing hazards to operators are also being developed [14.53]. Excavation and the loading and transport of the spoils are radio-controlled from a central control room located at a distance of 2–3 km from where the machinery is working. A vehicle with a radio relay station acts as an intermediary unit. The radio-controlled system incorporates the following subsystems:

- Transmission of stereoscopic images and graphics to a central control room.
- A bidirectional system for controlling vehicles and transmitting information about their position; the vehicles are located within a radius of 1 km from the radio relay station (Fig. 14.132).
- Audiovisual transmission providing information to the operators.
- Remote measurements using the GPS and an automatic tracking device (a three-dimensional laser positioning device).
- Monitoring the movement of the vehicles and the progress of the work and printing the results.
- Transmission of information about the excavation's cross-sectional dimensions and the positions and inclination of the vehicles.

Pneumatic Caisson Work

In pneumatic caisson work, because of the hazards (decompression sickness) to which the operators are exposed when moving from a pressurized space to atmospheric pressure, it is highly desirable to eliminate direct operation through automation [14.53]. Several methods of carrying out caisson earthwork have been developed in Japan [14.53]. One of these is a method of unmanned caisson work. The minimum diameter of a cylindrical caisson which can be used in this method is 8 m. If a rectangular caisson is employed, its minimum dimensions are 8.0×6.5 m. The preliminary work, which includes leveling of the ground to ensure even sinking of the caisson, is carried out using conventional earthmoving equipment. The system's common feature is remote control from ground level.

The equipment shown in Fig. 14.133 consists of a caisson scoop, a fast spoil-loading device, a caisson

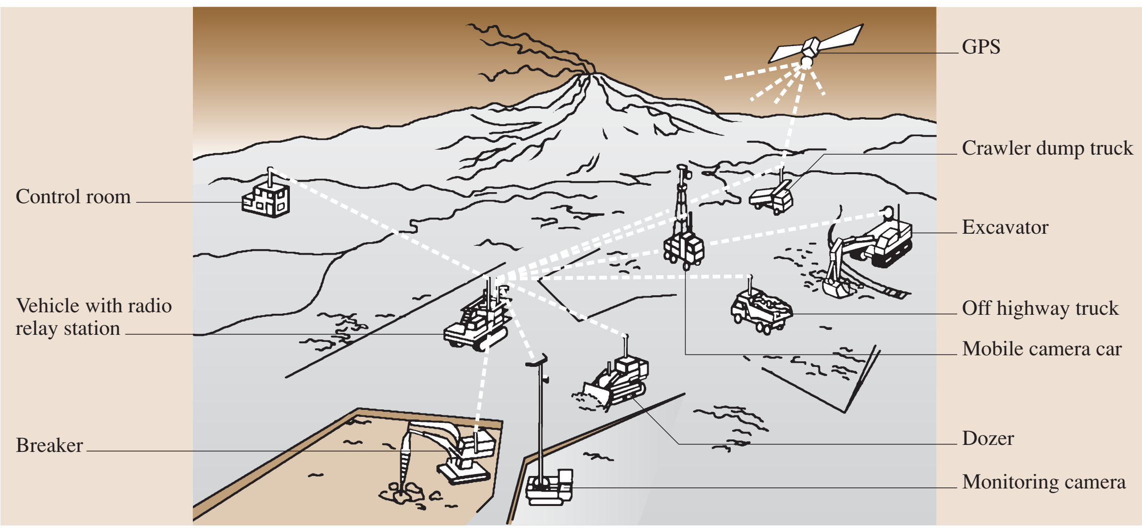


Fig. 14.132 System for remote control of earthmoving machinery

scoop control system, a measurement system, and a data transmission system.

The soil is excavated and transported by a specially designed caisson scoop that discharges its content onto a belt conveyor or the platform of a hoisting winch with a quick rotary-type spoil loader. Then the spoil is discharged into containers. The caisson scoop is radio-controlled and sensors installed on it monitor its operation.

Diaphragm Wall Construction

Diaphragm wall construction has been automated on construction sites in Japan. There are several commercially available systems for the erection of diaphragm walls. Automation covers excavation, the measurement of excavation execution accuracy, and quality control of the slurry stabilizing the excavation's walls and of the concreting process [14.53].

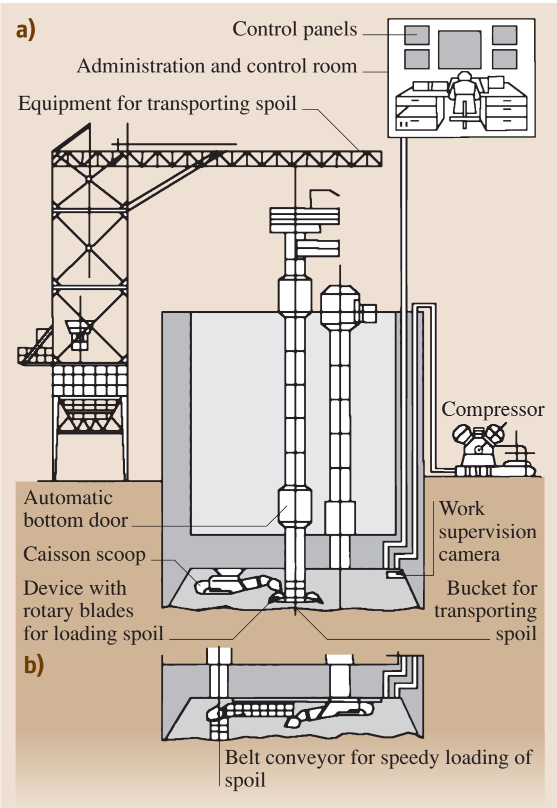


Fig. 14.133a,b Equipment used for unmanned caisson work: **(a)** equipment used in circular caissons **(b)** equipment used in rectangular caissons

An example of an automatic excavation system is the set of tools (Fig. 14.134) which was used for erecting a cavity wall of record dimensions (150 m deep and 2 m wide) in Izumiotsu near Osaka [14.53].

The system consists of a positioning system, an excavating system load control, and machine manual control by the operator on the basis of the information displayed on the monitor screen. The excavating unit, called an excavator, is suspended on a wheeled crane.

The measuring system consists of equipment located on two support structures and the excavators' instruments: adjustable guides, an inclinometer, a depth gauge, and a fuzzy controller to control excavation wall irregularity.

The position of the excavator is determined as a function of the horizontal shift of the two trace wires. The displacement of the trace wires is measured in an area of 100 mm^2 by a noncontact magnetic gauge with a junction measuring system.

The measuring system ensures accurate determination and correction of the excavator's position. For a 100 m deep excavation the excavating tool position accuracy is 30–50 mm.

Pile Driving

In the case of pile-driving machines, automation covers the control system ensuring the precise guidance of the working tool's end. A multijointed pile driver is shown in Fig. 14.135 [14.53].

The machine's main function is to drive in steel T-piles and sheet pile walls. In addition, various fittings, such as an earth drill or a vibratory hammer, can be attached to the multijointed work system's end. The machine is equipped with a computer-aided guidance system which guides the work system's end in the vertical plane as shown in Fig. 14.135. Before the new control system was introduced only a skilful operator simultaneously controlling the positions of the two arms had been able to make the work system's tip follow a linear trajectory. In the new system, which coordinates the movements of the two arms, control is effected by means of only one lever.

The computer-aided system of controlling the position of the work system's end ensures, by properly positioning the pile and maintaining its angle of inclination, that the pile is driven in accurately.

14.8.2 Automation of Concrete Work

Types of Concrete Works Covered by Automation

The automation of concrete works covers primarily the transport and distribution of concrete mix, and then the removal of the layer of corroded concrete from reinforced concrete structures, applying a new layer of concrete, the fabrication of reinforcement, the removal of irregularities in the surface of freshly set concrete, and the vertical shifting of formwork in the sliding erection process. Several applications of related techniques have been described [14.54]. The automation of concrete mix production in concrete batching and mixing plants is discussed in Sect. 14.3. Examples of the automation of the particular types of concrete construction tasks are provided below.

Transport of Concrete Mix

Most concrete mix transport automation solutions are found in the construction of dams [14.53]. The automation solution depends on the location and size of a dam. Figure 14.136 shows a diagram of an automatic concrete mix transport system used in the construction of a dam with a concreting work volume of 510 000 m^3.

The system covers the delivery of concrete mix from a concrete mixing plant to tipper trucks transporting it to the placing site. The fully automated system consists of the following devices: transfer car with a 4.5 m^3 capacity tank, two 4.5 m^3 capacity buckets, two cable winches with a hoisting capacity of 14.5 Mg, and two 9 m^3-capacity ground concrete hoppers. The transfer car draws concrete mix from the concrete mixing plant, transports it, and discharges it into one of the two buckets.

The operation of all the devices is controlled from a central control room. Information is displayed on a cathode ray tube (CRT) screen in the central control panel and, if necessary, the operator can intervene in the process. A basic requirement for the efficient functioning of the system is the precision positioning of the concrete buckets in the positions of concrete mix loading and unloading into hoppers. To ensure this, the bucket position is controlled in a spatial Cartesian coordinate system. The unloading of the buckets into hoppers is controlled wirelessly by means of systems with interlocking. The opening and closing of the hoppers gate valves is controlled by the truck drivers, who draw a specified quantity of concrete mix.

Besides computers and a program selector the other major components of the control system are gyroscopic sensors, optimeters, and coding units. Continuous speed control is employed in the cable winches' drives so that

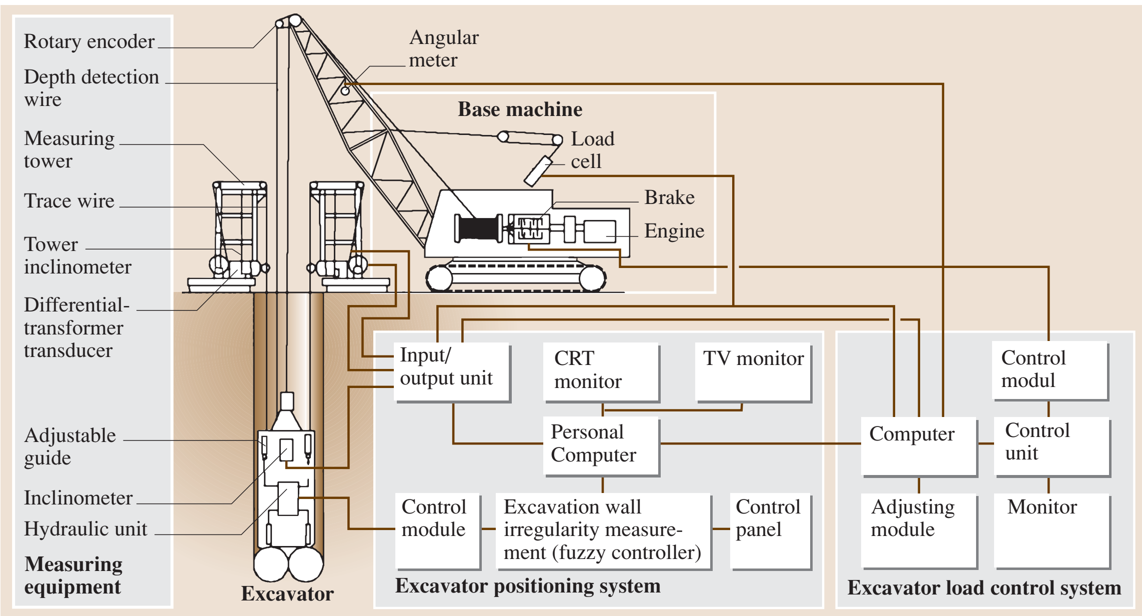


Fig. 14.134 Automatic diaphragm wall excavation system

the buckets can be quickly lifted and lowered, but positioned slowly.

Several concrete mix transport automated systems designed for the erection of dams are available on the Japanese construction equipment market.

Their common feature is the use of components such as transfer cars, cable winches, concrete buckets, hoppers, central control rooms, and radio-control systems. Instead of cable winches automated tower cranes can be used as the basic machines.

Distribution of Concrete Mix on Placing Site

Automation of concrete mix distribution is applied in the erection of large horizontal concrete structures such as floors and concrete bases. In this case, distributors fed by concrete pumps are usually employed [14.53]. Sometimes tower-mounted distributing booms are used, particularly in densely reinforced places where it is difficult to move distributors.

In order to be able to locate the delivery pipe's tip in the whole work area a typical distributor can perform the following work motions:

- Driving on a short (e.g., 3.2 m) portable rail-track
- Slewing of the whole delivery pipeline
- Mutual slewing of the particular pipeline segments
- Slewing of the flexible section of the delivery pipe

A concrete mix distributor with a capacity of 40 m^3/h (one of the smaller devices in this category) is shown in Fig. 14.137.

The distributor's delivery pipeline, which is 100 mm in diameter, consists of a steel pipe section and a hose, whose position can be changed in the vertical plane by means of the winch. The distributor can rotate at two points: at the junction with the travel section (on the track's axis) and at the junction with the rubber hose. In order to change its position the distributor is raised and turned by means of a jack lift and the rails are laid in a desired position. The distributor's whole delivery pipe can be rotated in the vertical plane in a range of $\pm 35°$ and the hose in a range of $\pm 108°$. Moreover the elastic section can be raised up to 10° and lowered to 30°. The distributor is radio-controlled and one of the control modes is *partially automatic*, which eliminates the difficult simultaneous operation of two levers.

Among concrete mix distributors there is also a system for large concrete works with a four-jointed 20 m long delivery pipeline and an automatic concrete mix distribution system incorporating an automatically controlled tower crane [14.53].

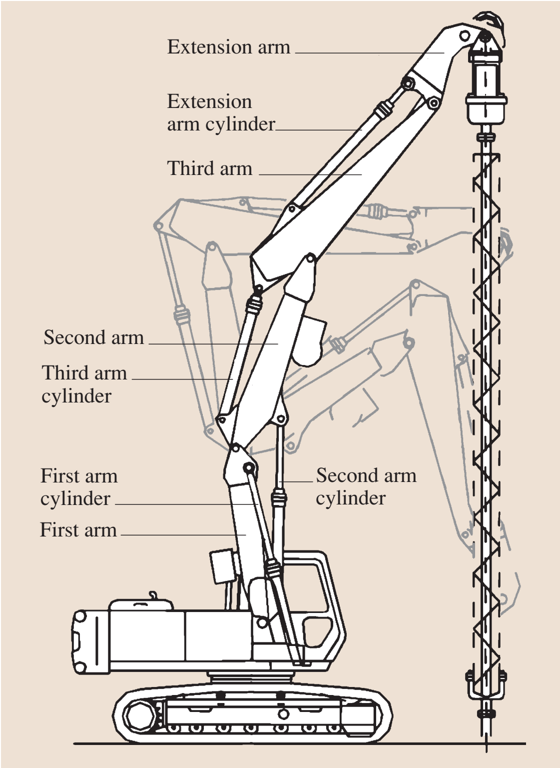


Fig. 14.135 Multijointed pile driver with automatic control of work system trajectory

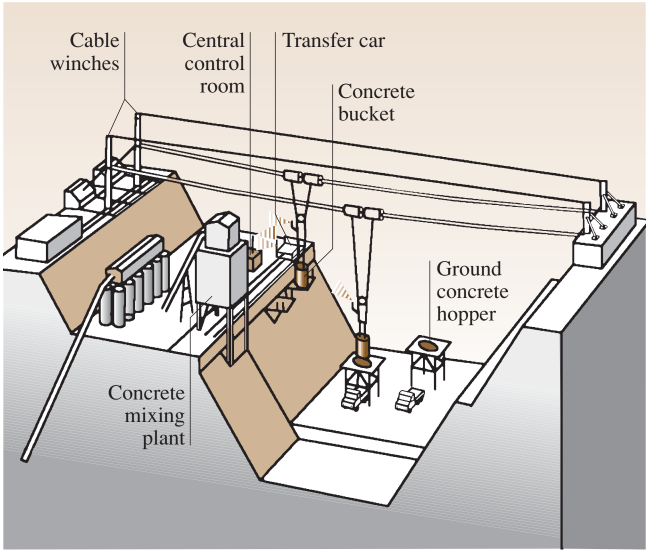


Fig. 14.136 Diagram of automatic system for transporting concrete mix on dam construction site

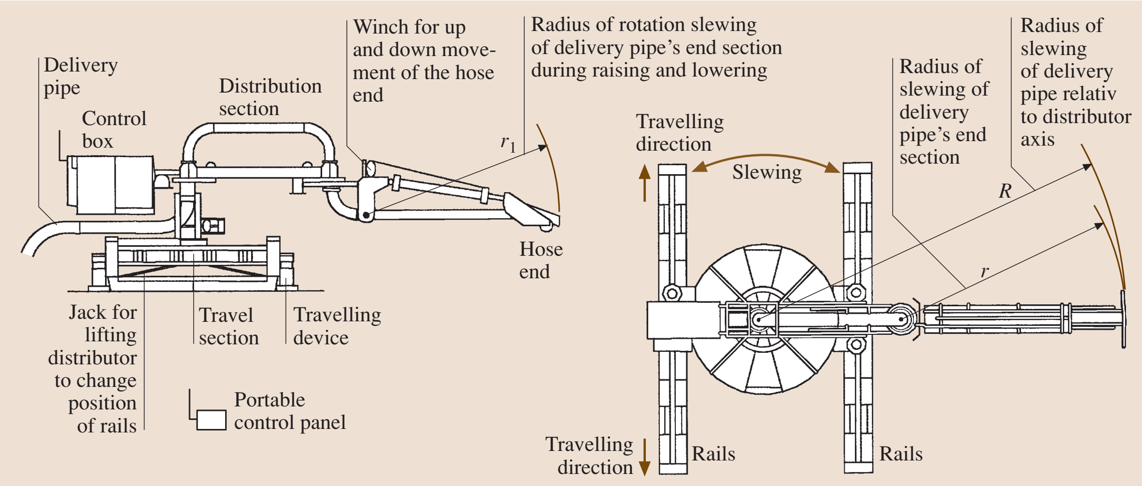


Fig. 14.137 Concrete mix distributor

For smaller structures, pumps with a distributing boom are employed [14.55]. Also here automation is introduced. One firm has developed *a computer controlled mobile concrete distributor* to distribute concrete mix on the placing site and better utilize the equipment.

Computer control makes it possible to position automatically the delivery pipe's elastic section from which concrete mix flows. In order to uniformly distribute concrete mix over the concreted floor one can select one of the three available modes of end section guidance. One of them is *follow-me*, shown in Fig. 14.138. The position of the pipe's elastic section is plotted in a coordinate system using a computer program. The operator sets the directions in which the elastic end is to move, directs the tip slightly in the desired direction (coordinates x, y), and toggles the switch up or down.

If the buyer wishes, the control system can incorporate the following modules:

- Fleet of vehicles management module (PD2000)
- Technical condition maintenance module (PARJS)
- Automatic stability control (ASC) module and automatic distributing boom control associated with concrete mix distribution

Concrete Spraying (Shotcreting)

The coating of reinforcement with a layer of concrete for anticorrosion protection purposes is used in new structures and for repairing old structures. The automation of this process is especially needed in the case of large surfaces, e.g., tunnels, pit shafts, and slopes in danger of sliding.

Research and development work aimed at automating shotcreting covers:

- Robots, incorporating devices for concrete mix proportioning, mixing, transport, and shotcreting; the robot shown in Fig. 14.139 [14.55] consists of a concrete mixing unit, a proportioning pump, and a remote-controlled robot arm. The robot arm is equipped with an automatically controlled oscillating nozzle which ensures accurate shotcrete application. Its action radius extends to 13 m, both

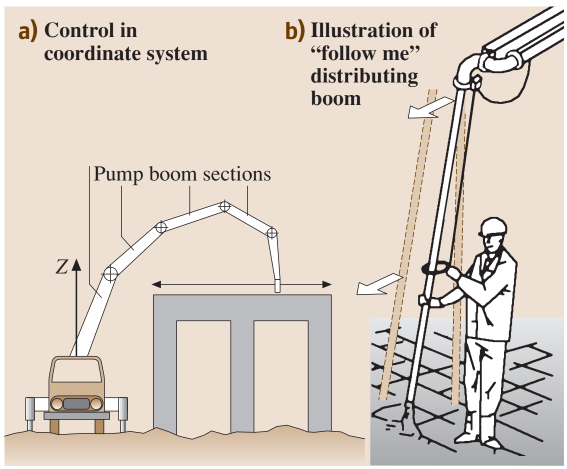


Fig. 14.138a,b Automatic control of delivery pipe's tip for concrete pump with *follow-me* distributing boom **(a)** control in coordinate system; **(b)** illustration of *follow-me* principle

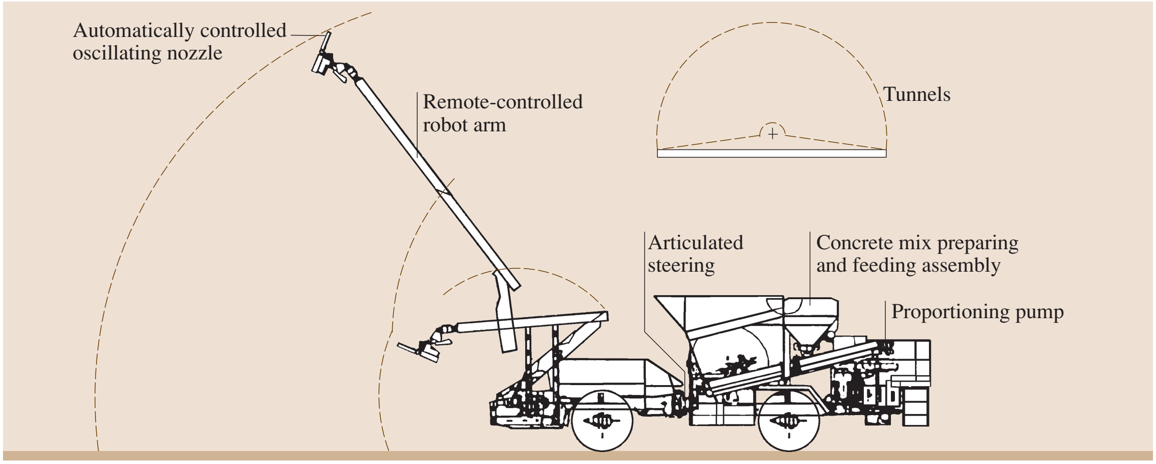


Fig. 14.139 Shotcreting robot

horizontally and vertically, and can easily be directed to cover all parts of the tunnel periphery. The concrete mixing unit consists of separate cement/aggregate bins with a total material volume of $5\,m^3$. The conveyance and mixing processes are effected by augers. All shotcreting is remote-controlled from a portable control panel, which enables the operator to choose the most effective position from which to work. The entire equipment is mounted on an articulated truck.

- A control system optimizes the amount of setting accelerant added to the concrete mix depending on the size of the concrete surface and the feed pump's delivery rate. The system can be used for any configuration consisting of a shotcreting device, a concrete feed pump, and accelerant feeder.
- Control equipment for secondary concrete lining placement. The equipment controls the quality of the shotcreted surfaces and automatically fills cavities at joints or cracks with concrete mix.

Removal of Surface Irregularities and Roughening of Freshly Set Concrete

The removal of surface irregularities and the roughening of freshly set concrete needs to be automated when erecting large concrete structures such as dams.

A robot for removing surface irregularities and roughening freshly set concrete is shown in Fig. 14.140 [14.53].

An automobile chassis with an attached assembly of four roughening brushes, a rolling sweeping brush, a threshold lift, and a waste bin is used as the suspension system.

The roughening brushes and the waste transport assembly can operate dry or with water supplied under pressure to the brushes and wastes removed by a vacuum pump [14.56].

Fabrication of Reinforcement

Reinforcement fabricating robots are used when erecting multistorey buildings with a reproducible system of storeys or on large construction sites such as nuclear power plants or underground reservoirs. A robot for the fabrication of reinforcement, mainly reinforcing bars, in both site steel yards and precast concrete plants is shown in Fig. 14.141. The objective is to reduce labor costs and ensure dimensional reproducibility of the fabricated elements. The robot automates simple, repetitive actions that steel fixers perform manually. Reinforcement with 4–6 m long longitudinal bars, 19–25 mm in diameter, can be fabricated. The robot consists of

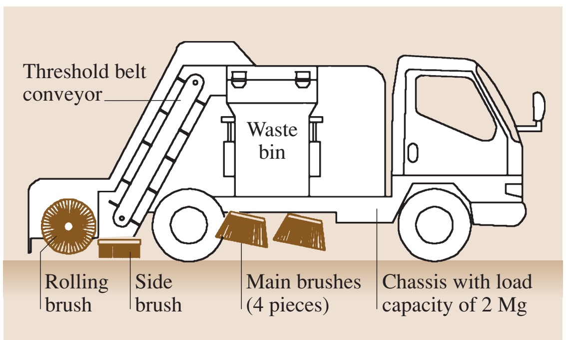


Fig. 14.140 Robot for removing surface irregularities and roughening freshly set concrete

the following assemblies: a base, an arm for feeding stirrups, an assembly for positioning stirrups, two (the upper and lower) automatic tying machines, a coil wire transfer car, arms supporting the (upper and lower) longitudinal bars, a power unit, and a control panel.

The main problem encountered when designing this robot was the precise longitudinal spacing of stirrups and securing them from shifting. This was solved by introducing a cam mechanism in which stirrups are positioned in the grooves of a plate that is shifted by the cam.

Other applications of robots to reinforcement fabrication include the following:

- Automated reinforcement pre-assembly line [14.53] designed for large structures and heavy rebars
- Automatic rebar bender and rebar column fabrication unit [14.53] designed for bending longitudinal rebars at an angle of 10–20° in six places and making a reinforcing cage

Removal of Damaged Concrete Layer in Reinforced Concrete Structures

Removal of a damaged concrete layer is used in repairs of structures such as bridges, pillars, tunnel walls, and dams, which have been damaged by the action of salts, environmental pollution and corrosion, or physical impacts. Two methods for the mechanized removal of a layer of concrete from a structure – a hydraulic method and a mechanical method – are distinguished.

In equipment operating on the hydraulic principle a highly pressurized (90–120 MPa) water jet penetrates the damaged layer of concrete and removes it at a rate corresponding to the operation of a few power hammers.

The advantages of the hydraulic method include: the possibility of adjusting the thickness of the removed layer through the rate of travel of the spray nozzle, eliminated dusting, a fixed magnitude of the acting forces (i.e., *healthy* concrete is not removed), and that rust can be removed from the reinforcement to be coated with a layer of concrete.

A limitation on the use of hydraulic equipment is ambient temperature, which cannot be lower than 0 °C.

Robots for removing a damaged layer of concrete by means of a high-energy water jet are shown in Fig. 14.142 [14.55].

The robot in Fig. 14.142a is equipped with a tower assembly kit providing an operating height 6 m. The robot shown in Fig. 14.142b removes damaged concrete from horizontal surfaces such as bridges and floors, but after reconfiguration can also be used on vertical surfaces.

The robot is controlled by a computer according to one of seven programs. All the machine travel parameters are set remotely from a control panel connected to the machine by a 4 or 6 m long cable.

In another robot operating on the hydraulic principle [14.53] a spraying nozzle whose work advance can be programmed through the association of slewing and advances was adopted. Such designs enable use in channels of circular and rectangle cross sections.

Accessories to hydraulic robots used for removing a layer of corroded concrete include 300 MPa feeders, distilled water tanks, and abrasive containers, in which cutting out holes in concrete structures becomes possible.

The number of robots available for the mechanical removal of a layer of corroded concrete is not large.

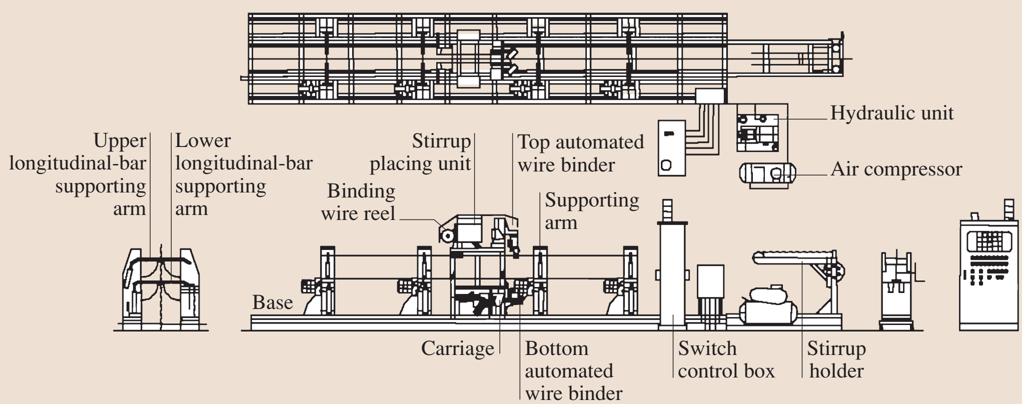


Fig. 14.141 Robot for fabricating rebars for reinforced concrete buildings

A *lining cutting robot* for work in tunnels resembling an ellipse sector in cross section is available [14.53]. The working tool is a rotary two-tool cutting head. The rotation of the head and the advance of the robot along the tunnel are controlled by a computer.

Forming of Concrete Structures for Sliding Forms

The automation of concrete structure forming mainly applies to sliding forms used in the construction of dams and structures such as chimneys, towers, silos, and bridge piers. A few methods of automating the erection of structures by sliding forms are described in [14.53].

14.8.3 Automation of Masonry Work

In European countries (Germany, the UK, and The Netherlands) research aimed at developing robots for masonry work has been conducted since 1991. This work has been focused on robots for erecting external and internal walls from aerated concrete and gypsum blocks.

A crane-manipulator (Fig. 14.143) for transporting and assembling $0.6\times0.9\times1.0$ m aerated concrete blocks has been developed in The Netherlands.

The prototype robot shown in Fig. 14.144 was developed as part of the European Rocco project in 1995.

Research on the mechanization and automation of block-work wall erection focuses on the following equipment:

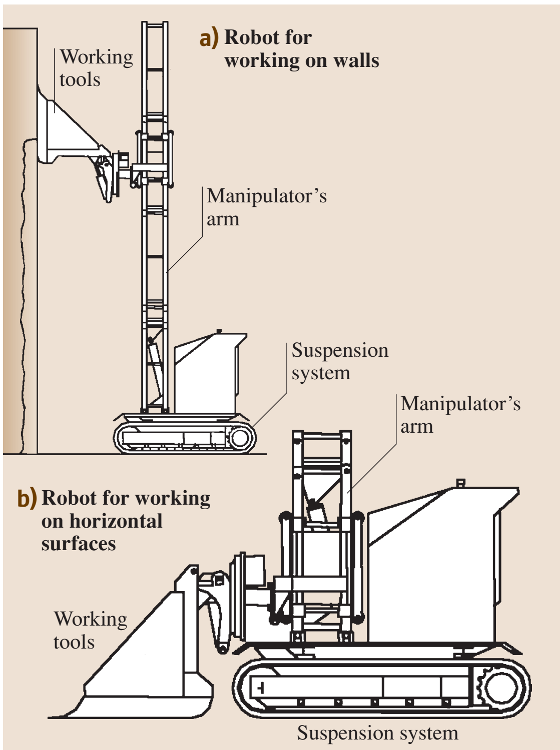


Fig. 14.142a,b Robots for removing damaged layer of concrete by means of a high-energy water jet: **(a)** robot for working on vertical walls, **(b)** robot for working on horizontal surfaces

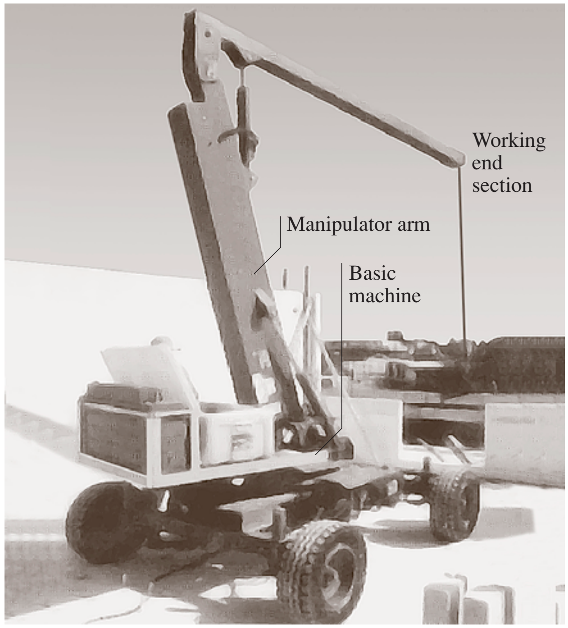


Fig. 14.143 Small-sized crane-manipulator for transporting and laying aerated concrete blocks

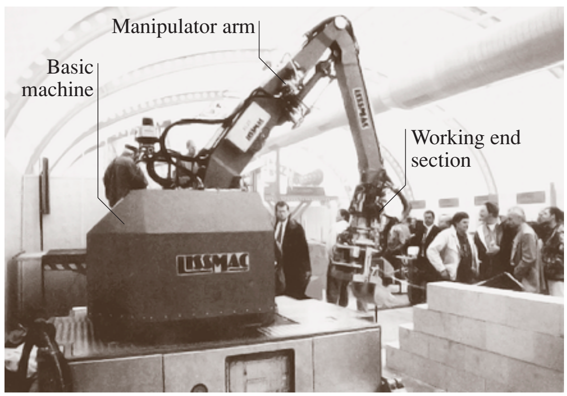


Fig. 14.144 Prototype robot for erecting walls of masonry, developed as part of the Rocco project

- Special bricklayer's platforms for adjusting the bricklayer's position to the height of the wall under construction
- Special winches or air-driven arms for compensating for the gravity of the blocks so that the latter can be manipulated weightlessly

Information on the numerous areas of research into robots for masonry work can be found in [14.45].

14.8.4 Automation of Cranes

The automation of cranes is connected with their specific use in a construction process. These are usually tower cranes (but also crawler hydraulic cranes) with an automatic control system, for transporting and distributing concrete mix and laying reinforcement.

A tower crane adapted for transporting and distributing concrete mix in housing construction is shown in Fig. 14.145.

The crane is a peculiar combination of the tower crane and the concrete pump's placing boom. The 32 m long four-sectioned boom can cover the entire work area. The final section of the boom concrete mix pipe is rigid (not flexible as in most cases) so that concrete can be placed accurately with no need to involve any workers.

Concrete mix is distributed from the level of the horizontally laid concrete mix pipe, whose position is remote-controlled. The elevation of the pipe above the concreted structure is constant and automatically maintained by means of computer control and a joystick. The position of the pipe's tip is specified in a Cartesian coordinate system on the basis of data (angles between the boom's particular sections received from sensors). In the case of joystick control, in order to maintain the boom horizontal, its position is automatically computed on the basis of the speed set by joystick and the current position of the boom. Joystick control allows one to move the first three boom sections in the vertical plane while the end section of the concrete mix delivery pipe remains horizontal. Depending on the application needs, the boom can be controlled automatically or manually.

Another example of the automation of cranes is an automated crane for transferring and arranging reinforcement (Fig. 14.146), intended for work on nuclear power plant sites. It can lay reinforcement at a rate of 0.05 m. No workers are needed to suspend the reinforcement bars, which can be arranged both horizontally and vertically by the system. The crane's specifications are:

- Maximum load: 1500 N
- Operating radius: 2.5–10 m
- Height of lift: 15 m

The crane is equipped with a special device for gripping rebars. The lifting and placing of the first rebar is manually controlled. This operation becomes automatic for subsequent rebars.

In [14.53] one can find more examples of the automation of crane control systems such as a crawler hydraulic crane for dam construction and a tower crane for the automatic distribution of concrete mix during the erection of a high-rise building.

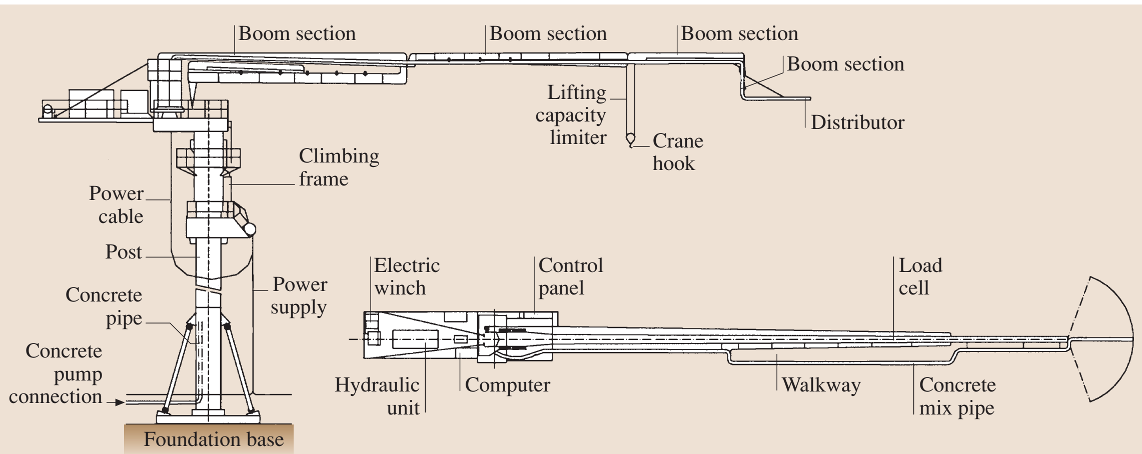


Fig. 14.145 Tower crane for placing concrete

14.8.5 Automation of Materials Handling and Elements Mounting by Mini-Cranes and Lightweight Manipulators

Mini-cranes and lightweight manipulators are used for materials handling, fitting building finishing elements, and transferring heavy construction equipment that cannot be moved manually. A radio-controlled mini-crane is shown in Fig. 14.147. The machine is intended for putting up aerated concrete block walls. This mini-crane with a three-sectioned telescopic boom has a lifting capacity of 500 N at an operating radius of 3 m. In its working mode the mini-crane is supported by four outriggers, whereas for relocation or transport it is mounted on a crawler chassis.

The crane can move up and down stairs and for transport can be fitted into a delivery truck. The crane's working dimensions are given in Fig. 14.147.

A lightweight manipulator designed for assembly work and transporting construction equipment inside buildings is shown in Fig. 14.148. Equipped with all kinds of attachments it can be used instead of interior work scaffoldings as a staging for ceiling work such as the fitting of lightweight beams, soffit, lightening, and heavy items. Its main advantage is that the position of the fitted element can be adjusted by means of the traversing and lifting gears operated from the handle attached to the manipulator's tip. Thanks to its small outer dimensions the manipulator can be moved through doorways and transported to different floors in the building's passenger lift. The manipulator has a lifting capacity of 150 daN and mass of 560 kg [14.53].

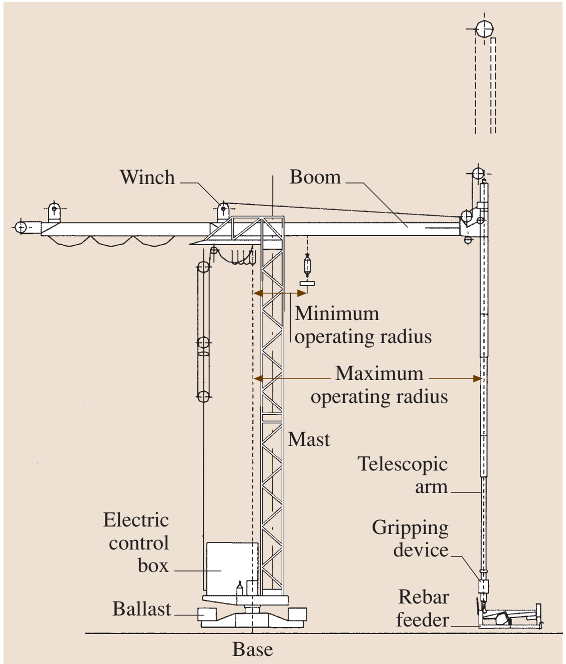


Fig. 14.146 Automated crane for transferring and arranging reinforcement

The offered mini-cranes and lightweight manipulators include:

- A mini-crane for fitting lightweight lining components, with a lifting capacity of 8000 N × 1.8 m, a lifting height of 5 m, a three-sectioned hydraulic boom, and a crawler undercarriage. It has an elec-

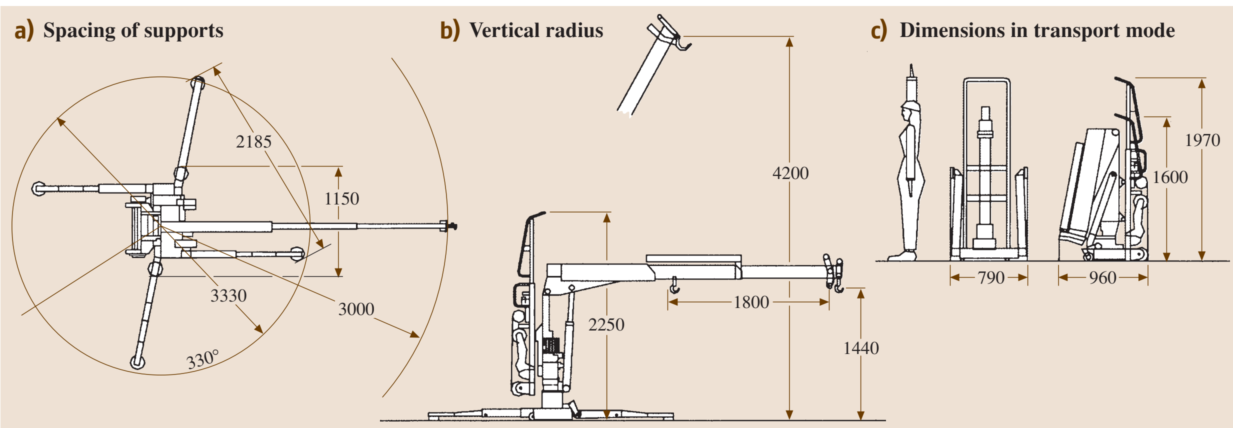


Fig. 14.147a–c Working dimensions of a mini-crane for erecting aerated concrete block walls: **(a)** spacing of supports; **(b)** vertical radius; **(c)** dimensions in transport mode

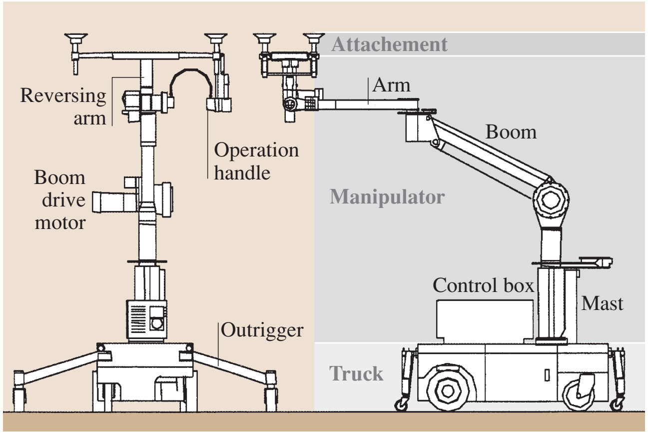


Fig. 14.148 Lightweight manipulator for finishing work

tric drive and a wired remote control. In order to make it possible for it to work in narrow rooms, the crane is equipped with a special mechanism, called the *dual-axis offset system*, which uses a combination of complex operations such as manoeuvring the winch while at the same time raising or lowering and extending or retracting the boom [14.53].

- A robot for transferring and positioning steel plates, weighing as much as 170 kg, used for reinforcing beams and columns in buildings located in seismic zones [14.53].
- A robot for fitting curtain walls made from panels, weighing as much as 250 kg, fitted between steel sections. The robot consists of a carriage with a wall panel gripping and transferring arm, positioning sensors, and a data-processing system which controls the fitting operation. The sensors on the arm determine the deviation between the appropriate position and the current one.

14.8.6 Automation of Construction Welding Work

Among construction welding work the welding of steel columns and beams is the focus of automation and robotization aimed at reducing welding work time and improving the working conditions of welders who, when hand welding on construction sites, are exposed to sparking, high temperature, and work at heights. The following devices for automating welding work on construction sites and prefabricating plants are available on the market:

- Robots for welding columns
- Robots for welding steel frames
- A device for automatic welding of girder braces

The robot shown in Fig. 14.149 is intended for welding columns together in steel construction. It executes horizontal multilayer welds. The whole column welding system consists of a robot with a wire terminal, rails attached to the column to allow the robot to travel, a control box, and a carriage for transporting the power source and a wire feeder.

The system also incorporates a welding control system. The shape of the weld between the columns is checked by laser sensors. The robot automatically selects the appropriate welding parameters from the system's database. By changing the shape of the guide rails and the control software the robot can be adapted to welding tubular columns.

Information about the steel frame welding robot and the device for automatic welding of girder braces can be found in [14.53].

14.8.7 Automation of Finishing Work

General Directions of Finishing Work Automation

A survey of the available literature indicates that automation and robotization are mainly applied to the following kinds of construction finishing work:

- Leveling, compacting, and smoothing concrete mix when making concrete bases

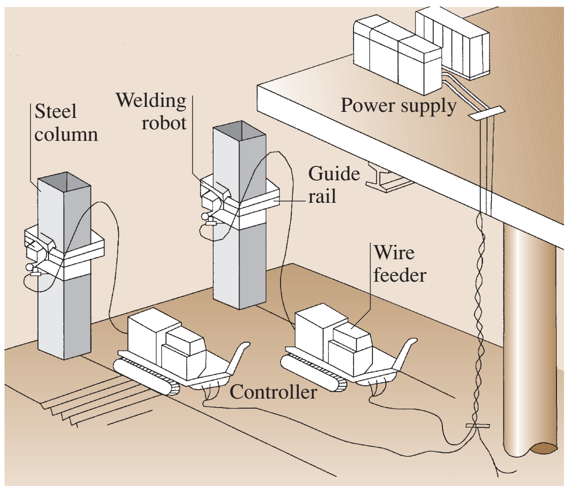


Fig. 14.149 Steel column welding robot

- Floating concrete bases and floors
- Painting
- Spraying fire-proofing materials on steel structures to protect them against damage by fire
- Laying tiles

Devices for automating the above finishing works are presented below.

Leveling, Compacting, and Smoothing Concrete Mix in Execution of Concrete Bases and Floors

Robots performing the function of a vibrating beam are used for precision leveling, compacting, and smoothing concrete mix when making concrete bases and floors.

The robot shown in Fig. 14.150 consists of the following units: a truss girder with a traveling mechanism, a working unit (composed of a leveling worm and a vibro-plate), saddles, and a control system. Leveling and smoothing are performed automatically by the working unit moving along the girder, i. e., perpendicularly to the movement of the robot. The maintenance of the base horizontal plane is controlled by a laser receiving set, an inclinometer, and a hydraulic cylinder, which automatically raises or lowers the working unit.

The robot is capable of leveling surfaces up to 15.5 m wide.

Another robot for screeding floors with a deviation from plane of ± 1 mm and a control system with two laser beam receiving sensors is described in [14.45].

Floating of Concrete Bases and Floors

The aim of floating is to impart smoothness to a concrete surface. Building floors on which fitted carpeting is to be laid must be floated.

Since the floating of concrete surfaces is often performed on construction sites, several types of robots controlled by radio or via an overhead conductor are offered [14.53]. Most of these are rotary floats with the working tools in the form of blades. In one exceptional model, six vibro-plates with a supersonic vibration frequency were adopted as the working tool. One of the models equipped with a traditional working tool in the form of rotating steel blades with an adjustable angle of inclination is shown in Fig. 14.151.

In the most common float models, the direction of the working travel is selected by appropriately inclining the floating disk, whereas the robot shown in Fig. 14.151 is equipped with a driving axle and an autonomous navigation system which allows it to determine its actual position and move along a programmed route (Fig. 14.152).

In order to program the robot it is enough to key in the dimensions *a* and *b*.

The robot is controlled via a wire. The travel control system consists of a microcomputer, gyrocompass, and a travel distance sensor. A touch sensor prevents the robot from bumping into obstacles. The robot's floating capacity is 500 m^2 per hour.

Painting

In painting work, robots are usually used to paint exterior walls. The next area where robots are employed is surface preparation for painting and surface preparation and painting combined.

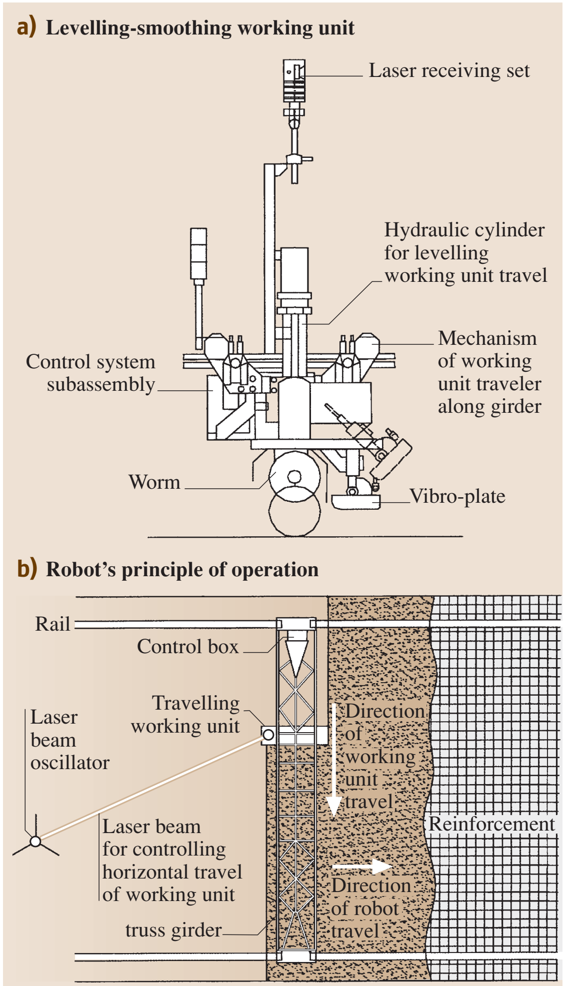


Fig. 14.150a,b Robot for finishing concrete bases and floors. **(a)** Leveling–smoothing working unit; **(b)** robot's principle of operation

One such robot for painting outer walls is shown in Fig. 14.153 [14.53].

The robot is mounted on a hanging scaffold and moves up or down and crosswise together with the scaffold.

Besides the scaffold and its drives and the robot itself, the system includes a control box, a control panel with buttons, monitoring equipment, and a paint-feeding unit.

The robot maintains a constant distance between the spraying nozzle and the building's wall. In order to apply paint uniformly, the nozzle's oscillatory motion is also controlled. To increase its painting capacity the robot is equipped with two spraying nozzles. The robot's average capacity is 200 m^2/h.

External-wall painting robots differ in their adaptation to construction site conditions (high-rise buildings with a complicated shape, or low buildings with simple design), and in their methods for reducing paint mist dispersion or eliminating unpainted areas. Paint can be applied by spraying nozzles or a roller. The preparation of a surface for painting consists of cleaning by means of a rotating cloth disk, with the dust being sucked off into a bag filter.

In the case of some robots, a surface is cleaned for painting by means of wire brushes or a shot-blast machine [14.53].

A robot for removing old paint prior to renovation painting removes paint using a jet of water flowing out under a pressure of 150 MPa. A pressure generator and a spraying nozzle are placed on a hanging scaffold attached to the wall by means of suction cups [14.53].

Spraying of Fire-Resisting Materials on Steel Structures

For fire protection the building's load-bearing structure must be coated with a layer of an insulating material – usually a 25 mm thick layer of rock wool. Because of the harmful effects of rock wool dust on the human body, workers manually spraying the semiliquid insulating mass must wear masks to protect them from inhaling harmful dust and wear special protective clothing.

Therefore it is vital to automate the insulating mass spraying operation and eliminate any direct participation of people in the application of the protective layer.

Two robots for coating structural beams with fireproofing mass are shown in Figs. 14.154 and 14.155.

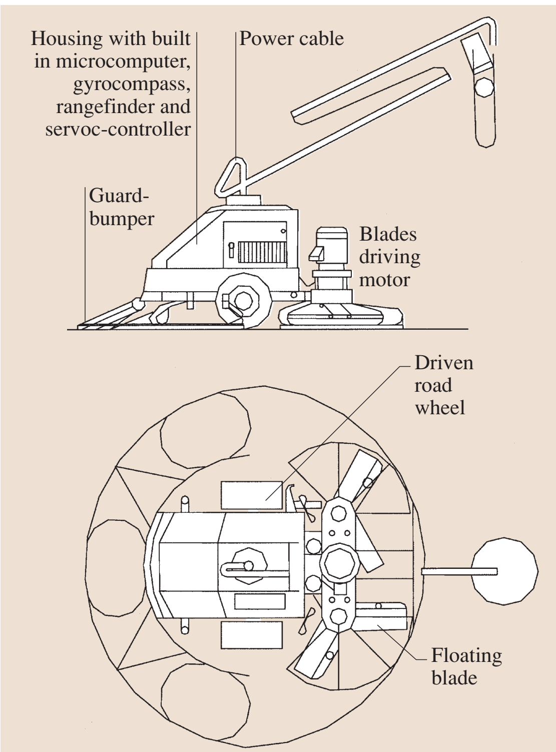


Fig. 14.151 Robot for floating concrete slabs

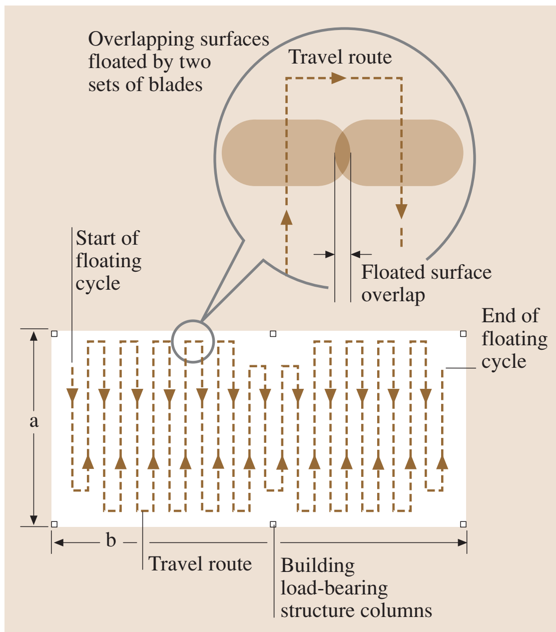


Fig. 14.152 Route of programmed robot travel in rooms with dimensions $a \times b$

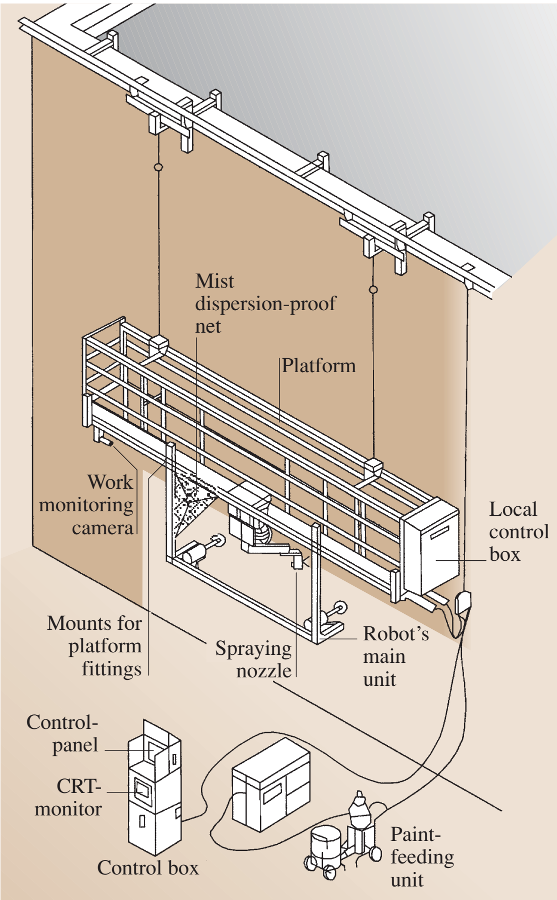


Fig. 14.153 Robot for painting exterior walls

The robot in Fig. 14.154 consists of two main fire-resistant mass preparation units (Fig. 14.154a) and the fire-resistance mass spraying robot proper (Fig. 14.154b). Once the beam's elevation and length are keyed in the robot starts moving, sensing its position by means of an ultrasonic sensor and spraying fireproofing mass on the section's bottom and sides. The spraying nozzle can be raised to a height of 2.8–4.4 m by means of a screw elevator. Special software makes the entering of robot operation data simple and easy.

The robot shown in Fig. 14.155 is intended for work in narrow rooms that are inaccessible to equipment operators. It consists of a carriage, an articulated arm with a spraying nozzle, and a control unit. The carriage has two sets of wheels: one for moving the robot longitudinally and the other for moving it transversely relative to the beam being sprayed with fireproofing mass. The articulated arm can rotate in both the horizontal and vertical plane and it can be moved to a distance of up 1500 m along the carriage's platform. Computer control enables the automatic combination of working motions for guiding the spraying tip.

Besides the described robots for spraying fireproofing mass onto structural beams one should also mention robots based on a typical industrial robot. An articulated arm with a spraying tip makes it possible to spray fireproofing mass on both horizontal and vertical surfaces [14.56].

Laying Wall Tiles

Laying tiles to form wall linings is an operation that is difficult to automate, mainly because of the requirement

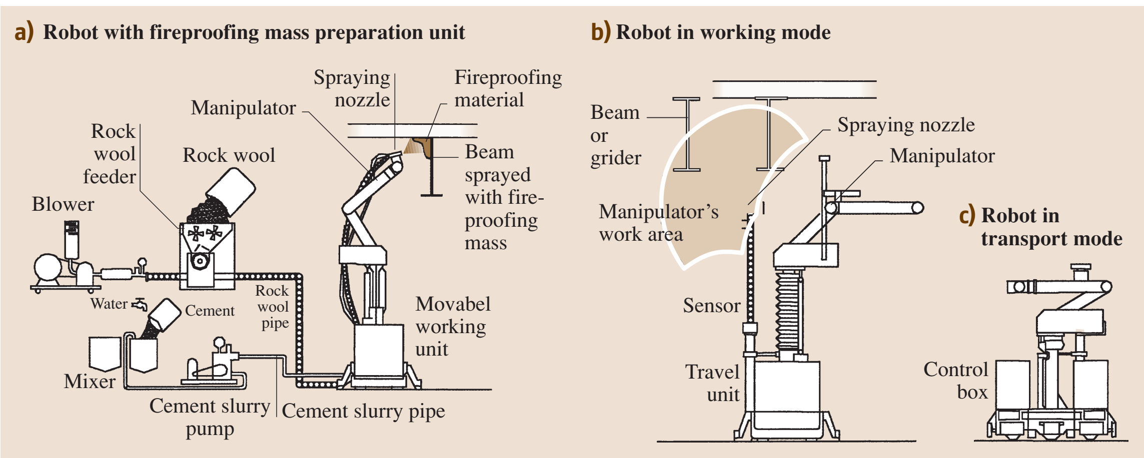


Fig. 14.154a–c Robot for spraying fireproofing material: **(a)** robot with fireproofing material preparation unit; **(b)** robot in working mode, **(c)** robot in transport mode

to spread adhesive or cement, which requires high positioning precision. Nevertheless, because of the large share of lining work in finishing work, attempts are being made to automate this field. Progress has been achieved by employing a rubber belt conveyor with suckers so that several tiles can be laid simultaneously. Tile-laying robots are mainly used for covering with large surfaces of exterior walls with tiles. A tile-laying robot moves on rails fixed to scaffolding. A robot for laying tiles on the building's facade, developed jointly by several Japanese companies, is shown in Fig. 14.156.

The robot is intended for laying 227×60 mm (8–15 mm thick) tiles on traditional mortar. Its daily capacity is 14 m^2. For comparison, a craftsman is able to lay 7 m^2 in this time.

More information about the robot can be found in [14.53].

14.8.8 Automated Building Construction Systems for High- and Medium-Rise Buildings

Automated building construction systems (ABCS) for high- and medium-rise buildings were developed in Japan as a measure to alleviate the labor shortage in the construction industry. Fourth-generation robots, designed according to the principle of design for robotic construction (DfRC) integrating robot design, building erection, and the materials, are employed for the realization of buildings in such systems.

Prefabrication of structural elements and adherence to the schedule of materials delivery to the construction site are of vital importance.

The benefits from using ABCS include: labor saving, improvement in work safety, and a reduction in construction time, stemming from the minimization of labor and protection against inclement weather (the working platforms are provided with roofing).

The following features of ABCS can be distinguished:

- *The automated transport of building structural components*, i.e., columns, beams, flooring slabs, and exterior walls from a storage place to the construction site (where they are built)
- *The use of prefabricated components* so that forming and working on the construction site are eliminated
- *Just-in-time delivery* of the required components
- *Automatic positioning and fixing of components*: the prefabricated components of columns and structural beams, floor panels, outer walls, and modular piping are automatically positioned in the appropriate

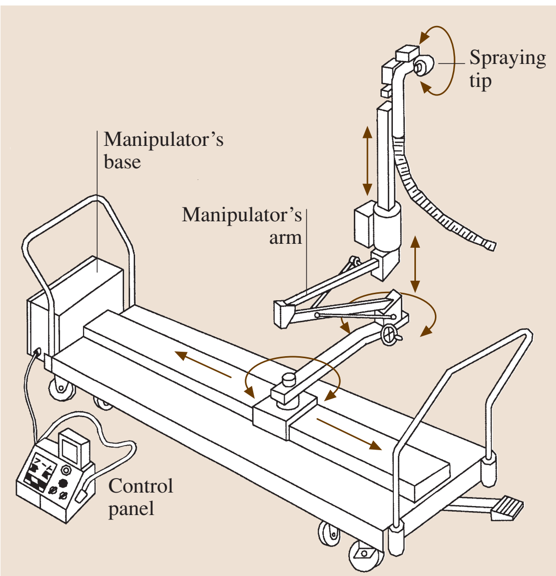


Fig. 14.155 Robot for spraying fireproofing rock wool mass in small rooms

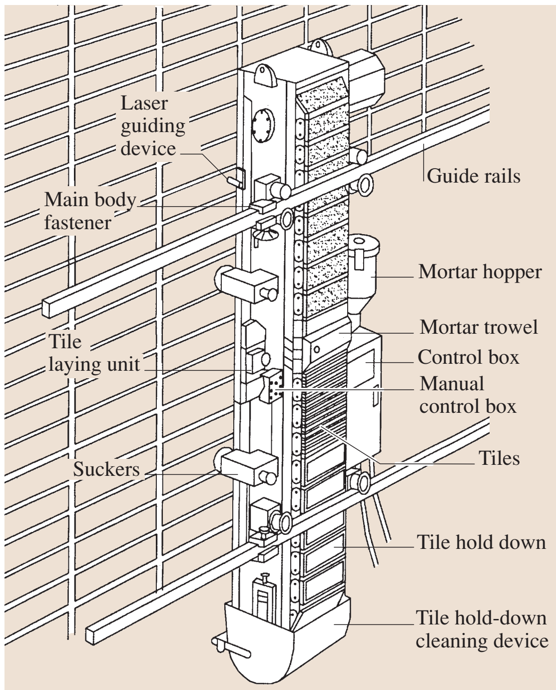


Fig. 14.156 Robot for laying tiles on building elevation

places, welding robots weld the structural components together, and the exterior walls are fixed by quick-connect fittings
- *Raising (by means of hydraulic lifts) of the support structure* with the suspended overhead cranes (the working platform) for the construction of the next storey
- *A building design that takes into account work automation*, sot that all building components and their joints lend themselves to automated transport and assembly

The existing ABCS can be divided into the following three groups:

- Those employing a special support structure (situated above the building structure under construction) for suspending overhead cranes and hoisting winches [14.57]
- Those using the roof structure or the top floor as the working platform for fixing transport-assembly equipment
- Those consisting of the construction of successive storeys on the zeroth level and the raising of the constructed part of the building

In all the above construction systems it takes 5–8 days to build one storey.

ABCS are used for erecting mainly steel-frame buildings, but also prefabricated reinforced concrete buildings [14.58].

Only a few of the many ABCS have stood the test of time and proved economically and technologically viable.

Selected ABCS are described below.

ABCS Employing Special Support Structure for Suspending Overhead Cranes and Winches

A construction system based on a special support structure for suspending overhead cranes and traveling winches during the erection of a steel-frame building is shown in Fig. 14.157.

The basic equipment for work realization in this system includes the support structure with a suspended

Part B | 14.8

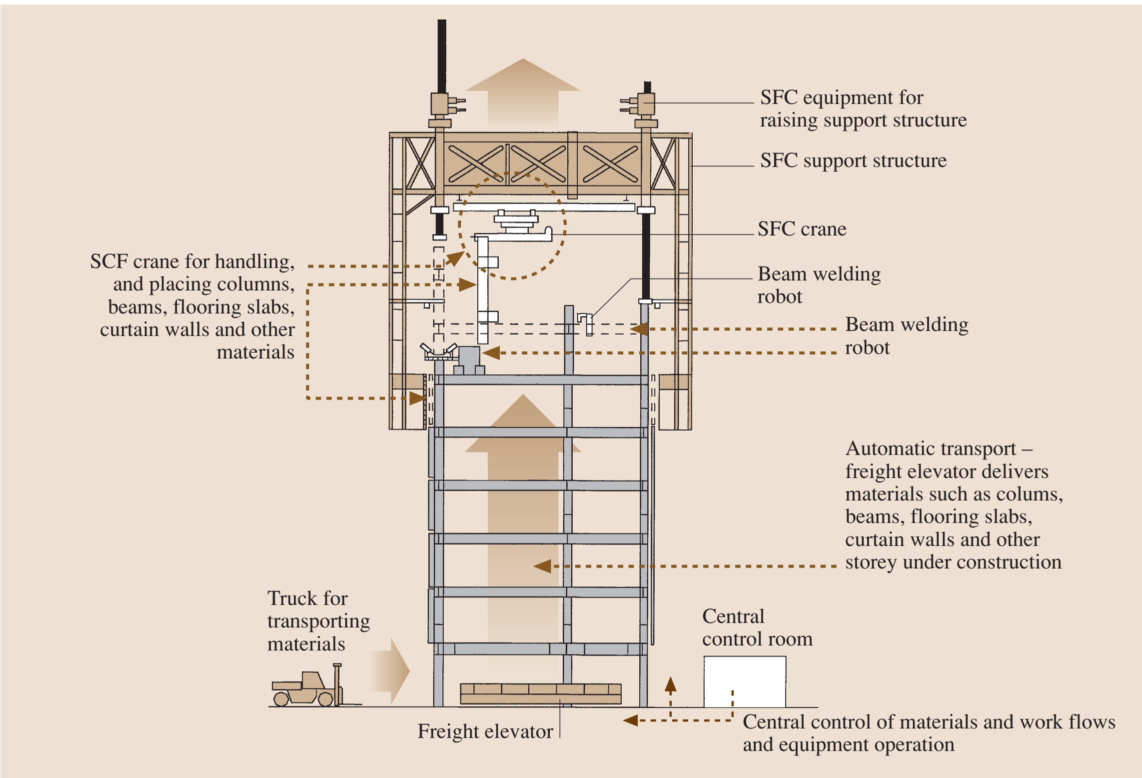


Fig. 14.157 Schematic of ABCS for erecting steel-frame buildings. SCF – the support structure with a set of equipment located on the top storey is called a super construction factory (SCF)

overhead crane and robots for welding the building's columns and structural beams. The support structure's weight is carried by the building under construction. The crane's operation is automated and coordinated with an elevator delivering materials in the appropriate sequence. Welding robots are attached to a floor or beams by one-touch fasteners. All operations are controlled from a central control room.

An ABCS for constructing buildings from prefabricated reinforced concrete slabs, referred to as *Big Canopy*, is shown in Fig. 14.158. This system has been developed by the Obayashi Corporation of Japan.

The special support structure, called a canopy, is supported on four corner posts.

Three assembly cranes and winches, each with a hoisting capacity of 7.5 Mg, are suspended from the canopy. Structural members are transferred to the storey under construction by a traveling crane, a fast building elevator, and a combination of overhead cranes and winches in order to provide access to the entire assembly area. The canopy is raised every two storeys.

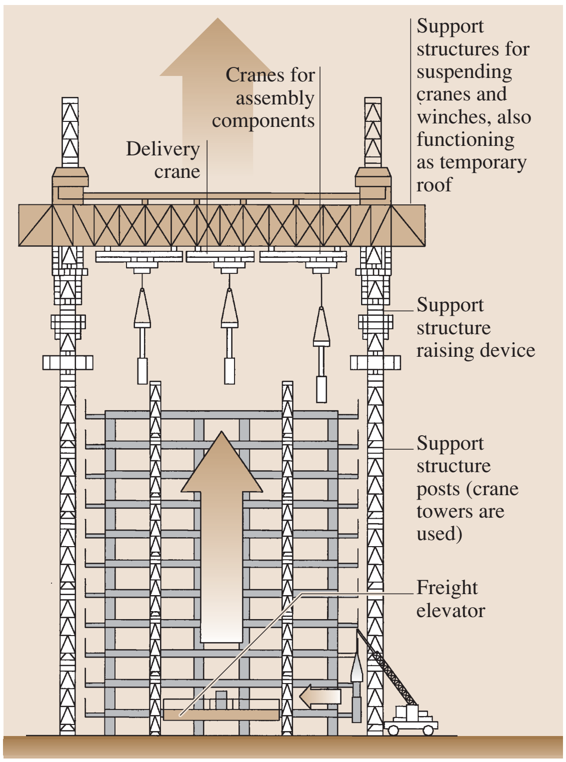


Fig. 14.158 Schematic illustrating the erection of a reinforced concrete building using the Big Canopy system from Obayashi Corporation

Finishing materials are transferred to the places where they are to be built-in during the erection of the load-bearing walls. The main part of the canopy is dismantled once the building reaches its full height, while its perimeter frames are jacked down and dismantled on the ground.

The automatic control covers the delivery of building components from the stacking yard, their transfer within the building, and their assembly. The components are identified by plates bearing a bar code which includes the position in the building and basic specifications.

ABCS Using the Roof or Top-Floor Structure as a Working Platform

Construction systems using the roof or top-storey structure as the working platform constitute the most numerous group of ABCS. A schematic of one such system which uses the top floor as the platform for the assembly of the steel load-bearing frame and reinforced concrete flooring slabs is shown in Fig. 14.159. The system is called the Shimizu manufacturing system by advanced robotics technology (SMART) [14.53, 59].

Construction starts with the assembly of a roof (hat-truss) and a special support structure for suspending overhead cranes and traveling winches The two structures are assembled on the ground and then jacked up using a system consisting of four tubular pillars equipped with lifting gears. A single lifting gear consists of two rings (the top one and the bottom one) and three hydraulic cylinders between them, each with a lifting capacity of 120 Mg and a working pressure of 12 MPa.

Once the roof is raised, the first storey is built. When it is completed, the roof with the support structure is jacked up one storey. Then the lifting system is also shifted up and supported on the load-bearing beams of the previously erected storey. As the individual storeys are constructed, structural building components (reinforced-concrete flooring slabs, interior and exterior walls, and utility systems) are fitted. Even though one storey weighs about 1200 Mg, it takes only 1.5 h to jack up the roof with the support structure and shift up the lifting gear.

In order to provide protection against bad weather the roof and the periphery of the storey under construction are lined with screens.

SMART embraces the automatic handling and assembly of building components, welding by robots, the raising of the roof and the structure for suspending overhead cranes and winches, protection against

adverse weather conditions, and a computer building construction control system. Because of its integration of the automation of the particular kinds of construction work with control systems, SMART is considered to be a state-of-the-art system.

Besides the described systems, several other systems based, among others, on the idea of constructing consecutive storeys on the zeroth level and successively lifting up the constructed parts of the building have been developed. Besides Shimizu and Obayashi, a number of other Japanese engineering construction firms have developed their own proprietary systems with similar functionality, e.g., Taisei, Kajima, Takenaka, Fujita, and others. Buildings up to 15 storeys high are erected with the use of these systems.

14.8.9 Automation and Robotics in Road Work, Tunneling, Demolition Work, Assessing the Technical Condition of Buildings, and Service–Maintenance Activities

This section provides a general overview of systems developed in this area and the reader is referred to the additional technical literature on the subject for further details.

Automation of Road Work

Automation and robotization of road construction and maintenance presents unique sets of challenges and opportunities, as described in [14.60]. Roadwork includes earthwork, concrete work, and other works connected with road trench cutting, road-base making, and the placement of pavement. In this section, only the machinery connected with the automation of pavement work is presented. It seems that automation in this field has focused on laying of asphalt mixture and road profiling.

Robots with all the pavement work operations automated are available in industry [14.53, 55]. The operations include transfer of asphalt mixture from delivery vehicles, feeding and spreading of asphalt, steering of the machine along a fixed route, paving rate control, and the start–stop control of all the operations. The asphalt paver operator does not need to pay attention to the loading of fresh asphalt mixture or driving the machine along a fixed route; their main task is to watch the screed to ensure that a high-quality pavement is obtained.

The asphalt paver's computer control system controls the following parameters:

- The thickness of the placed layer of asphalt mixture – the current paving thickness is displayed on the cab's monitor.
- The road profile – the operator can automatically change the paving thickness at one end or the other end of the screed.
- The uniform feeding of fresh asphalt mixture to the screed.

Part B | 14.8

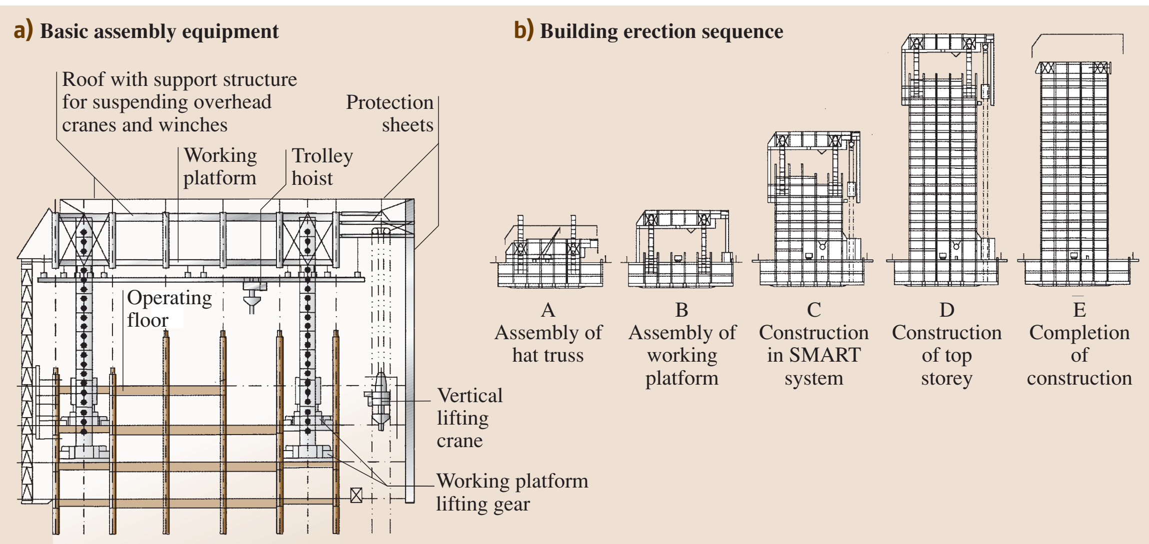


Fig. 14.159a,b SMART system for erecting steel-frame buildings: **(a)** basic assembly equipment; **(b)** building erection sequence

- The amount of crown.
- The uniform distribution of temperature on the screed.

Another machine is a hot in-place recycling machine intended for laying reclaimed asphalt pavements (RAP), which:

- Mills the pavement undergoing renovation, heated up by a preceding machine
- Prepares new asphalt mixture, which includes: reclaimed asphalt, fresh asphalt mixture delivered from an asphalt mixing plant, and chemical additives
- Lays a new layer of asphalt mixture

The hot in-place recycling machine consists of two separate, self-propelled units loosely connected by a conveyor. The set's front unit is composed of a feeder of fresh asphalt mixture delivered from an asphalt plant, a milling subunit, and a subunit for spraying additives. The rear unit consists of a reclaimed-asphalt pavement feeding and weighing subunit, a fresh-asphalt mixture batching unit, a mixer, and a subunit for laying new pavement. The two units move independently towards the destination, but operate in tandem.

The machine's automation covers: distance maintenance, the harmonization of the two units' driving speeds, the preparation of asphalt mixture, and feeding the mixture to the screed and laying it.

An example of a high level of automation is a road milling machine equipped with an automatic cutter control system (ACCS). With ACCS the machine can work in two modes:

- Contour-following mode, in which a constant cutting depth relative to the road surface is maintained
- Longitudinal and transverse contouring mode, in which the cutting depth is progressively adjusted to the required lateral differential

The cutting depth can be accurately adjusted to compensate for longitudinal and transverse unevenness in the pavement.

The cutting depth data for the road section to be milled are entered into the onboard computer, which automatically controls the position of the working tool in the selected operating mode.

Automation of Tunneling Work

The automation of tunneling is essential because of the hazard to people and the difficult working conditions, which are similar to those in underground mining.

The main aim of automation is to eliminate the presence of workers in the danger zone where they could be exposed to headwall landslides and inrushes of underground water in a confined space. Tunnel construction owes its rapid development to automation. The construction of municipal transport tunnels in urban areas, mini-tunnels for utilities (particularly for sewage pipes), and mountain tunnels for intercity transport is a major factor in the economic development of cities and regions. The general trends in the automation of tunneling work are presented below. Extensive information on tunneling machines and equipment can be found in [14.53].

The automation of shield tunneling covers the following operations:

- The automatic transport and assembly of prefabricated tunnel lining units, for which several systems of automatic lining transport and assembly have been developed for the different kinds of lining joints used
- The control of shield advance along a programmed route
- The complex automation of: tunneling, tunnel heading stability and shield advance control, output transport, lining assembly, and filling the space behind the lining with cement
- Shotcreting the lining's top layer reinforcement.
- Fabrication of reinforcement for the monolithic tunnel lining layer.
- Screeding of the top layer of the tunnel's invert.
- Transport and assembly of prefabricated concrete slabs for the tunnel's railway subgrade.
- Diagnosis of tunneling shield defects.

Most automation solutions are found in the areas of automatic transport and assembly of tunnel lining components and control of shield advance along a fixed route.

The automation in the construction of mountain tunnels covers the following aspects:

- Tunnel boring – when the start button is pushed the boring machine bores the ground in the tunnel's face, maintaining the tunnel's design cross section and following the fixed route with a high degree of accuracy. The available machine designs are capable of boring tunnels in hard and semi-hard rock without using explosives.

- The construction of a pre-lining (the pre-lining support method – PLS) to protect the tunnel face and adjacent structures against ground settlement; the pre-lining is made by excavating the soil around the tunnel face circumference and filling the slit with concrete; the PLS machine is equipped with a set of five augers or a chain cutter.
- The construction of another monolithic tunnel lining, using the vibration method to compact concrete mix.
- Tunnel face determination and marking prior to tunneling.
- Shotcreting of the lining's surface layer
- Determination of the position of explosive charges in the tunnel face
- Measurement and investigation of the fractured region and the strata in the ground ahead of the tunnel face
- Ventilation of the tunnel during its construction

A discussion of tunneling work automation should include the automation of mini-tunnelling. Mini-tunnelling is used in the construction of municipal sewerage and water-supply systems, gas grids, and so on without open excavations and the associated traffic problems. The technique consists of sinking two shafts (working chambers) at the start and end of the pipeline's route, boring a mini-tunnel by means of a tunneling shield, removing the excavated material, and forcing through pipes to form the mini-tunnel's lining (Fig. 14.160). The spoils can be removed mechanically (on conveyors) or hydraulically, being transported in suspension (partially recoverable). Equipment for boring mini-tunnels 250–4000 mm in diameter, running straight or curvilinearly, is commercially available. Mini-tunnels longer than 1000 m require intermediate working chambers. This technique can be used even in rocky soils.

Automation of Demolition Work and in Repairs of Building Structures

The aim of the automation of demolition work and in repairs of building structures is to increase productivity, reduce costs, and improve the working conditions of the laborers by improving their safety and reducing their physical effort. The devices presented below are used for crushing bricks, stones, and concrete, repairing cement kilns and metallurgical furnaces, and removing the surface layer of concrete in structures undergoing renovation. Several robots have been developed for these purposes. Depending on the size of the reduction tools, they can be divided into two groups:

- Robots equipped with mechanical tools, e.g., a hydraulic hammer
- Robots equipped with hydraulic tools using a high-pressure water jet

The two groups of machines have different ranges of application. Robots equipped with a hydraulic hammer and other fittings are designed for crushing building materials and for repairs, whereas those using a wa-

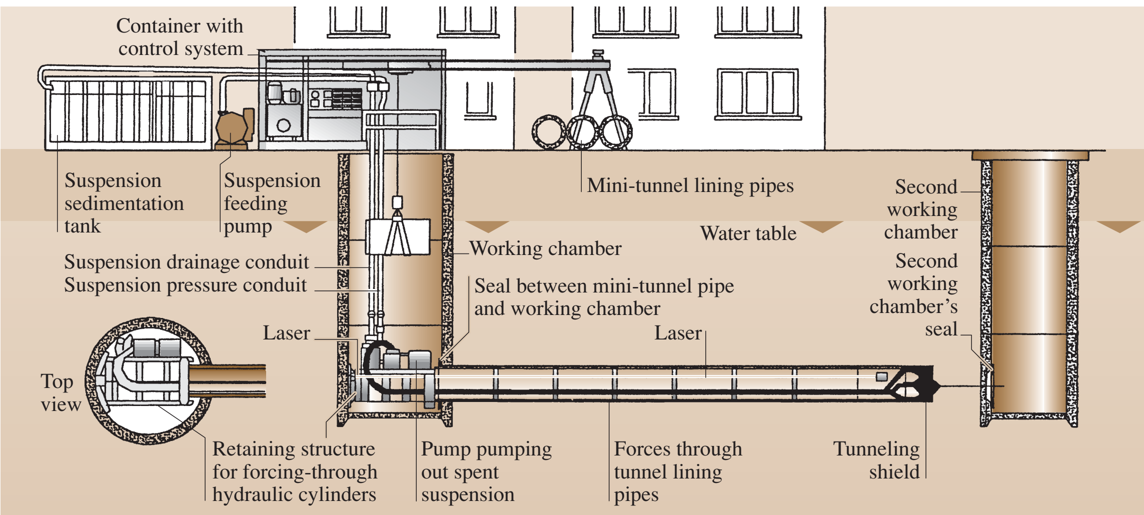


Fig. 14.160 Illustration of a mini-tunneling technique:

ter jet are intended for removing a damaged layer of concrete.

In the group of robots equipped with a hydraulic hammer one can distinguish, depending on the installed power and the tool's reach, small, medium, and large machines. Machines for small jobs are equipped with a 4 kW electric motor, medium machines have 11–15 kW motors, and large machines are powered by 22–30 kW motors. Their horizontal operating radius is, respectively, 2.4 m, 4.4 m, and 6.5 m.

These robots can be mounted on wheeled or track chassis. The robot shown in Fig. 14.161 is equipped with a 30 kW motor and electrohydraulic drives. Its three-sectioned boom allows one to accurately position the working tool within the operating radius. Apart from the hammer, the machine can be equipped with other working fittings: concrete shears, breakers, and pulverizers. The robot is remote-controlled from a portable control panel.

Instead of the electric motor, a diesel engine or a diesel–electric drive can be used as the prime mover. The boom's fittings include: a hydraulic breaker, crushing jaws, a loader or excavator bucket, and a gripping device. Detailed information about demolition robots can be found in [14.55].

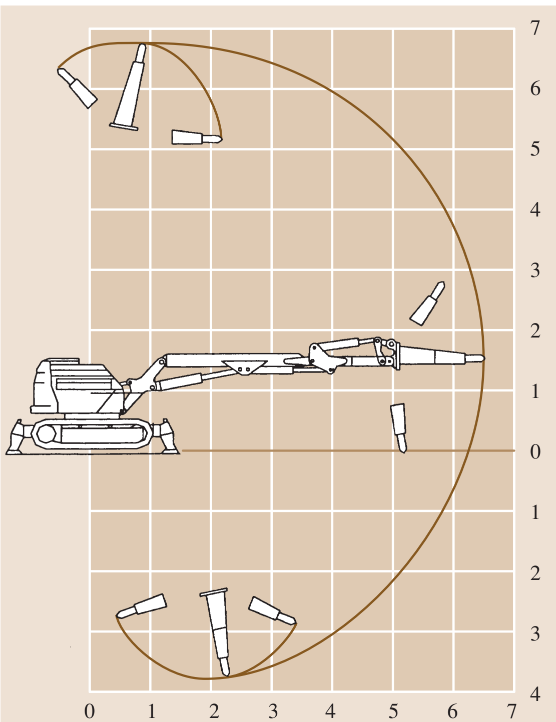


Fig. 14.161 Operating radius of robot with 30 kW motor for demolition work and material size reduction

Robots for Assessing the Technical Condition of Building Structures

Robots for checking the technical condition of building structures, referred to as inspection robots, are used for inspecting the following elements:

- Exterior wall facings
- Utility piping
- Concrete structures such as water dams and bridges
- Underwater structures

The most numerous in this group are tiled elevation inspection robots. Depending on their function, they check the adhesion of tiles to the base or check for layer corrosion. As time passes, adhesion decreases and, since the tiles may start falling off the wall, it becomes necessary to inspect the tiled walls at regular intervals.

A schematic of a robot for checking the adhesion of tiles to the building's elevation is shown in Fig. 14.162. The robot is drawn up on by a chain secured to the roof edge.

The check is conducted by continuously tapping the lining with ten small balls arranged in a row and analyzing the sounds generated. The diagnosis results, including the tapping locations, are transmitted to a computer on the ground, saved on a diskette, and represented graphically. The robot can also be used to assess the adhesion of plasters. It can operate at a rate of 700 m^2/day [14.53].

Besides tapping tiles with balls, other techniques are used to check the adhesion of tiles to the elevation, e.g., vibrating the wall and measuring the vibration characteristic. These vibration measurements are subjected to an analysis that differentiates between the frequency distributions of unstuck and adhering tiles.

Another inspection robot diagnoses layer corrosion of lining tiles. It moves on walls and is equipped with a tapping unit, a directional microphone, and an analyzer. Exfoliation is assessed on the basis of acoustic wave attenuation characteristics.

An automatic piping corrosion inspection system is intended for diagnosing the technical condition of cold and hot water systems. The inspection system can be used to check damage to 50–150 mm-diameter pipes. It measures wall thickness in a range of 1.5–9 mm by means of ultrasonic probes. A probe scanner mounted on a pipe automatically travels along the pipe, maintaining appropriate contact with it. A data processing and control unit controls the traveling and scanning move-

ments of the scanner and processes the data from an ultrasonic thickness meter [14.53].

Owing to the small diameter (150 mm) of its body and its four thrusters, a robot for the visual inspection of underwater structures can work in narrow passages, and even in pipes. A camera mounted on the slewing gear provides a wide view. The robot can work to a maximum depth of 30 m [14.53].

Depending on the user's needs, a robot for checking the technical condition of concrete structures such as bridges can be equipped with various fittings for:

- Nondestructive testing of structures
- Servicing and maintaining high-rise buildings
- Cleaning and renovating building elevations

The robot serves as a carrier for equipment and can climb vertical surfaces made of various materials. A special mechanism (with patented kinematics) with extremities in the form of vacuum suction cups [14.55] enables the robot to move on such surfaces.

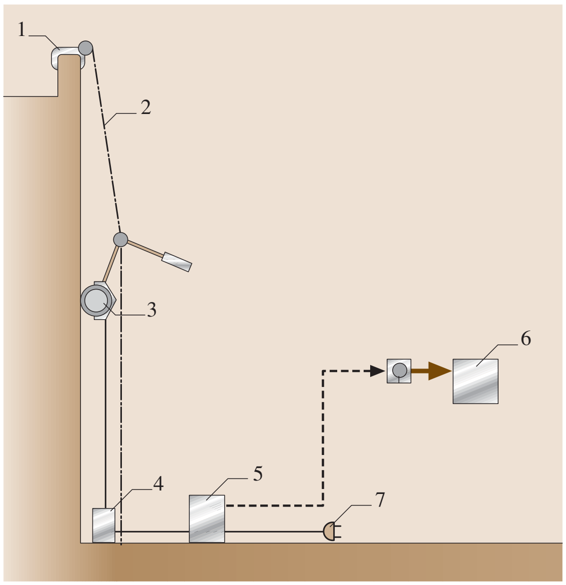


Fig. 14.162 Schematic of robot for checking adhesion of tiles to building's elevation (*1* securing robot to roof edge; *2* chain; *3* robot (hoisting gear motor and carrier of: tile adhesion diagnosing balls, analyzing circuit, and driving and communication control circuits); *4* power supply unit (performs various robot positioning functions); *5* winch controlling computer (position recording and communication control circuits); *6* output units (computer, *X–Y* plotter); *7* 100 V AC power supply plug)

Cleaning and Renovation of Building Elevations

Cleaning and surface-finishing tasks in buildings present a cost-effective opportunity for the application of robotics [14.61]. Several robots and automated devices for the cleaning and renovation of building elevations are available on the equipment market. Depending on the kind of elevation material (facing boards made from mineral materials, glass, etc.) appropriate renovation methods are used.

Elevations made from mineral facing boards are cleaned by blasting with an abrasive, by brushing or spraying with high-pressure water. Both the abrasive and the water are collected for reuse [14.53, 55]. Glass elevations are washed with hot water and detergents by robots equipped with sets of cylindrical and wheel brushes [14.55].

Room Air Cleanliness Monitoring

Room air cleanliness monitoring robots measure the following:

- The amount of dust in the air; in one measuring position the device collects three samples at different heights and determines the occurrence of dust divided into different diameter fractions [14.55]
- The room's environment characteristics (air flow, air pollution, temperature, and humidity) [14.55]

Cleaning of Construction Equipment

Construction equipment cleaning devices includes the following [14.62]:

- An automatic system for cleaning aluminum scaffolding boards
- An automatic washing station for cleaning the undercarriages of construction machines

The system for cleaning aluminum scaffolding boards removes concrete and dirt particles adhering to the board by means of high-pressure (40 MPa) water jets (Fig. 14.163) and ultrasonic vibration.

After washing with six high-pressure water jets the board is subjected to ultrasonic vibration. Fourteen vibrators are installed at the bottom of a large tank in which the board is immersed. In order to increase washing efficiency degassed water is used.

In the automatic washing station for cleaning the undercarriages of construction machines, washing is carried out in three stages: low-pressure water washing, high-pressure water washing, and low-pressure and

high-pressure water washing combined. The main components of the washing station are: water spraying and purifying equipment and a washed-out mud removal installation. Machine-specific automatic cleaning programs are used. All the pumps, the water purification circulation, and the removal of washed-out mud are controlled as a whole [14.53]. Force control of the robotic manipulator plays an important role in achieving successful automation of the cleaning tasks [14.63].

Surveying for Construction

Modern surveying techniques for construction are based on the global positioning system (GPS), which uses artificial satellites. The GPS has been upgraded so that it can be used in construction. The new surveying techniques are labor-saving and highly effective and do not require visual contact between the surveying stations. GPS surveying can be conducted across barriers, such as mountains or buildings, which make visual contact impossible. Moreover, surveying can be conducted in adverse weather conditions, such as fog or rain, 24 h a day, and with high accuracy.

The available surveying systems for GPS-based terrain projection use fixed datum points in combination with a mobile surveying station mounted on a truck or in the form of a remote-controlled crawler robot. Datum coordinates are transmitted to a point whose position is known [14.53, 56].

These surveying systems find application in the building of dams, roads, airports, housing estates, and so on.

Robot Implementation Issues in Construction

Construction is the single largest contributor to the national economies of most developed nations. However, the level of automation and robotization in this industry falls significantly behind that in manufacturing and many service-oriented industries [14.64]. Much of the predictions made in 1980s regarding the widespread use of robotics in construction by the beginning of the 21st century have not yet materialized. However, the core technologies and the prototypical applications of robots in a wide variety of construction tasks have been successful, as outlined in this section. Much research and development remains in order to reach the full application potential of robotics in this highly fragmented and diverse industry [14.65, 66]. New areas for future research in this domain focus on systems engineering work to redesign and re-engineer construction tasks and work sites to meet the capabilities of construction equipment. The theoretical foundations for this research were developed in the late 1980s and during the 1990s [14.67–70], but widespread support and investment from the construction industry in most countries, with the notable exception of Japan, is still mostly lacking. It is expected that the advent of applications of advanced sensor technologies and sensor networks, as well as integrated construction management systems utilizing enterprise resource planning (ERP) technologies and web-based project portals, for construction site instrumentation will contribute to significant growth of integrated, rather than single-use, fleets of robotics for application in this industry [14.69, 70].

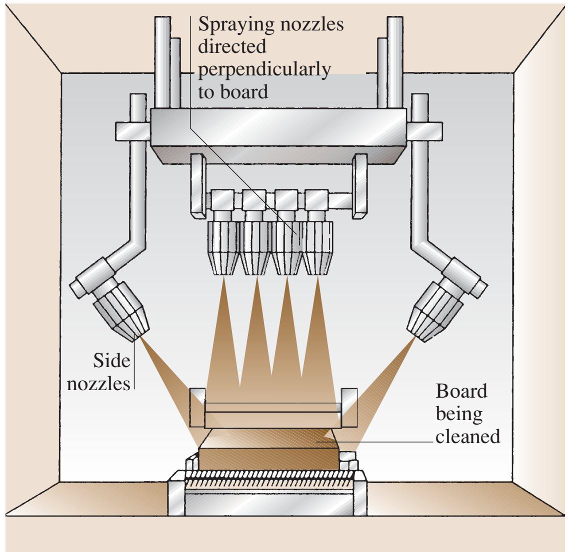


Fig. 14.163 Cleaning of aluminum scaffolding boards, stage I: cleaning with high-pressure water jets

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